THE STEAM ENGINE:

A TREATISE
ON STEAM ENGINES AND BOILERS.

COMPRISING THE PRINCIPLES AND PRACTICE OF THE COMBUSTION OF FUEL,
THE ECONOMICAL GENERATION OF STEAM, THE
CONSTRUCTION OF STEAM BOILERS;
AND
THE PRINCIPLES, CONSTRUCTION, AND PERFORMANCE OF STEAM ENGINES—
STATIONARY, PORTABLE, LOCOMOTIVE, AND MARINE,
EXEMPLIFIED IN ENGINES AND BOILERS OF RECENT DATE.

ILLUSTRATED BY ABOVE 1300 FIGURES IN THE TEXT, AND A SERIES OF FOLDING PLATES, DRAWN TO SCALE.

BY

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HALF-VOL. IV.

BLACKIE & SON, LIMITED,
LONDON, GLASGOW, EDINBURGH,
AND NEW YORK.
1890.

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SECTION IV.

THE CONSTRUCTION OF STEAM ENGINES (CONTINUED).

OTHER SPECIAL STEAM ENGINES (*continued*).

RAILWAY LOCOMOTIVES.

The brake-strap is of plate iron, ⅝ inch thick and 11 inches wide, and is applied to one-fourth of the circumference of the drum. It can be brought into action either by foot-pressure or by steam-pressure, from the platform. The power is applied through a lever of which the arms are 8 feet and 1 foot long. To the shorter of these the strap is connected. To the longer end a 10-inch steam-cylinder is connected, having an available length of stroke of 3 feet. The cylinder is closed at both ends, and the steam is distributed by means of an ordinary slide worked by hand. The lever consists of two 9/16-inch steel plates, riveted together with an intermediate flitch of pitch-pine. The central gudgeon is of steel, having 5½-inch journals.

The drum weighs 60 tons, and the total finished weight of the engines and drum together is 200 tons. The working pressure of steam in the boiler is 80 lbs. per square inch, and the factor of safety in the design of the engines is 10. The maximum speed attained by the pistons is about 700 feet per minute, when the engine makes 50 revolutions per minute. The engines are designed for raising 80 cwts. of net coal from a depth of 700 yards; and the gross load lifted, including 5¼ tons of rope, is about 12 tons. Steam of 80 lbs. pressure per square inch is supplied from four Lancashire boilers, 7 feet in diameter, 30 feet long.

On a recent examination of a pair of winding engines like those described, but wanting the improved valve-gear and drum, the wear and tear of the working parts, during nine years of heavy work, were found to be practically nothing. Part of the time, the work was carried on day and night,—the engines winding 32 cwts. of coal each lift in 45 seconds, from a depth of 495 yards. Another pair of engines in the Wigan district are winding 40 cwts. of coal in 30 seconds from a depth of 400 yards.

The special advantages of the winding drum here described are, smoothness of working, and diminished wear and tear of ropes. On such drums, ropes have been known to last from three to four years; whereas on ordinary drums, the life of a like rope is only 12 months.

CHAPTER XLV.—BLOWING STEAM ENGINES.

PAIR OF VERTICAL CONDENSING BLOWING STEAM ENGINES FOR THE RIO TINTO MINES, SPAIN.

DESIGNED AND CONSTRUCTED BY MESSRS. ROBERT DAGLISH & CO., ST. HELEN'S, LANCASHIRE.

(Steam-cylinders 22 inches in diameter; blowing-cylinders 54 inches in diameter; strokes 4 feet.)

Blowing steam engines, like engines for other purposes, have been constructed with beams and vertical cylinders, direct-action vertically, direct-action horizontally, and otherwise. The vertical direct-action engine appears to combine in the best manner the qualities of simplicity, compactness, convenience, and efficiency. The blowing engines of Messrs.

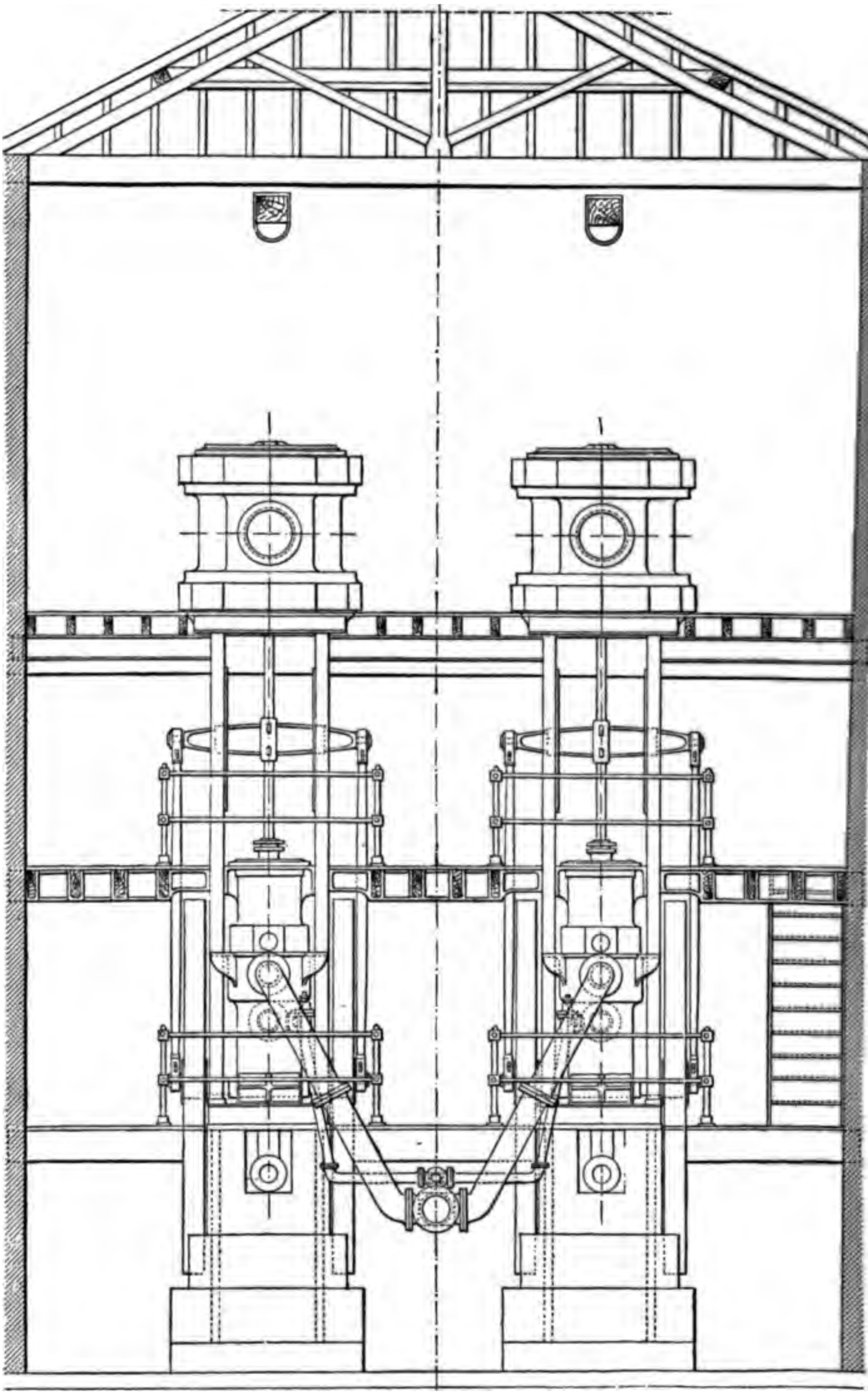


Fig. 728.—Vertical Condensing Blowing Steam Engines, by Messrs. Daglish & Co.: Front Elevation. Scale 1/72d.

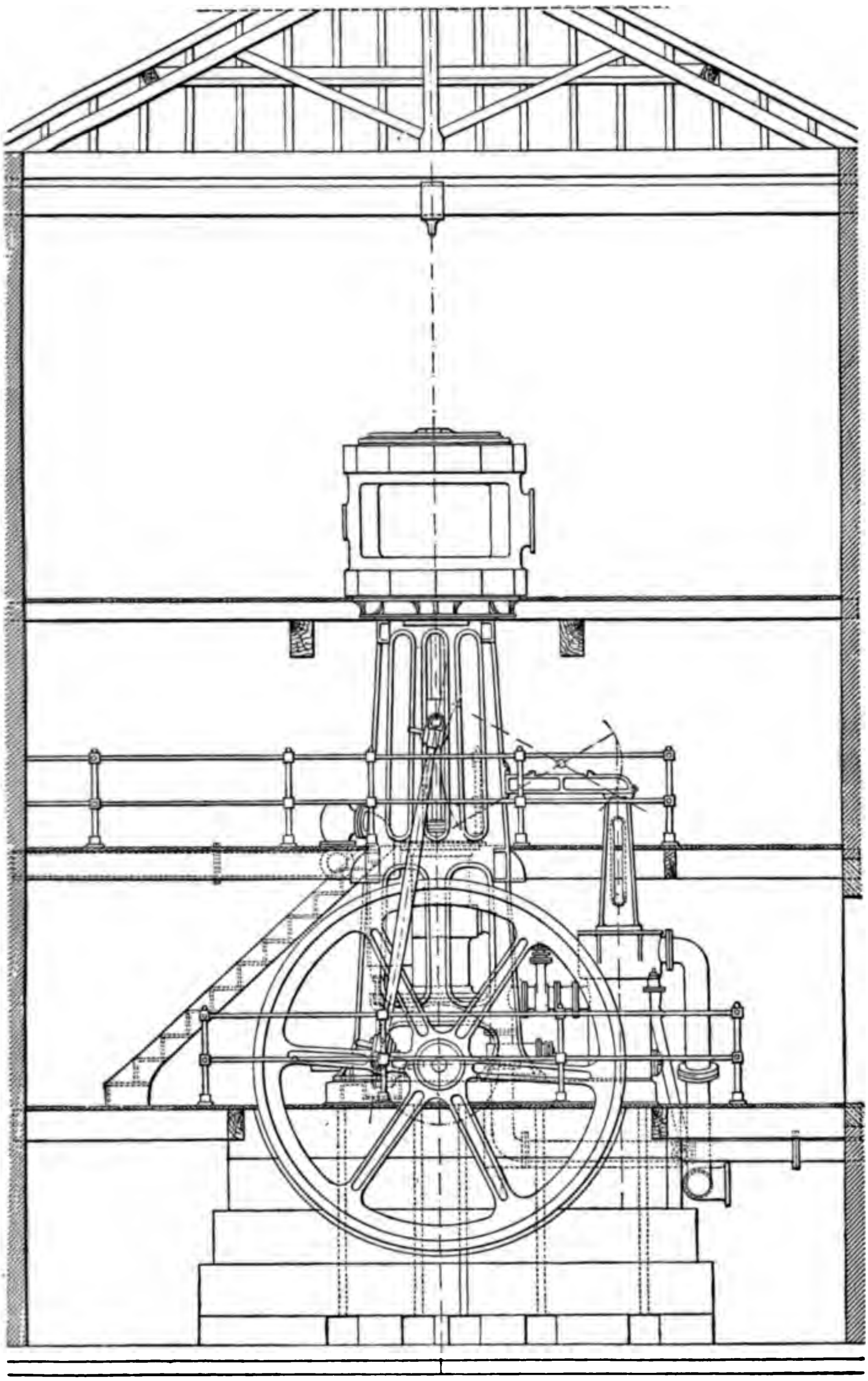
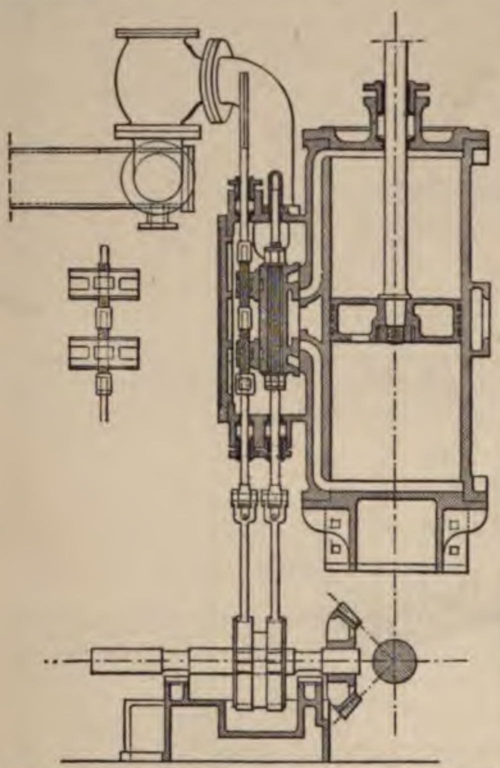


Fig. 729.—Vertical Condensing Blowing Steam Engines, by Messrs. Daglish & Co.: Side Elevation. Scale 1/72d.

Daglish & Co., figs. 728 and 729, were constructed for service in the pyrites mines belonging to the Rio Tinto Company, Spain, and erected in 1882. They are employed for the supply of blast of 3 lbs. pressure per square inch, to cupolas employed in the smelting of copper.

The two engines are erected side by side on independent foundations. The main shaft of each engine is carried in bearings on the foundation or sole-plate; and the steam-cylinder is immediately above it. The blowing-cylinder is over the steam-cylinder, on the same vertical centre-line, and is supported on side frames, to which the steam-cylinder is attached. The piston-rods of the blowing and steam cylinders are cottered into the crosshead intermediate between them, so as to form one rod. The ends of the crosshead are connected by connecting-rods to the main shaft. The pistons travel at the rate of 240 feet per minute, equivalent to 30 turns of the main shaft per minute. The working pressure of steam is 40 lbs. per square inch.



Figs. 730.—Daglish's Blowing Engine: Section of Steam-cylinder and Valves. Scale 1/32d.

The bed-plate, or sole-plate, of each engine, is of cast iron, 4 feet wide, 10 feet 10 inches long, 9¾ inches deep, hollow, of 1-inch metal. It is open in the middle, each side being square in section, having a top 12 inches wide, and two sides.

The vertical framing consists of a frame at each side of the steam-cylinder, ribbed or hollow, of 1-inch metal, bolted to the base-plate. Each frame is 5½ feet wide at the lower end, and tapers to 3 feet 10 inches wide at the upper end. The two frames are 3 feet apart.

The steam-cylinders, figs. 730 and 731, are 22 inches in diameter, with a 4-feet stroke, of 1¼-inch metal. Each cylinder bottom is formed with side brackets, by which it is bolted to the frames. The cover and the bottom are bolted to the cylinder with twelve 1-inch bolts and nuts, pitched at about 7½ inches of pitch. The steam-ports are 10 inches by 2 inches; the exhaust-port is 10 inches by 4 inches; respectively $^1/_{19}$th and $^1/_{9.5}$ part of the area of the cylinder. The bars between the ports are 1½ inches wide. The steam is exhausted through a passage 10½ inches by 1¾ inches, cast round the cylinder, from which it passes to the condenser.

The piston, figs. 730, is of cast iron, hollow, of ⅞-inch metal, 7 inches thick, in one casting. It is fitted with three packing rings of cast iron, 1 inch wide, let into grooves turned into the rim. The piston-rod is of

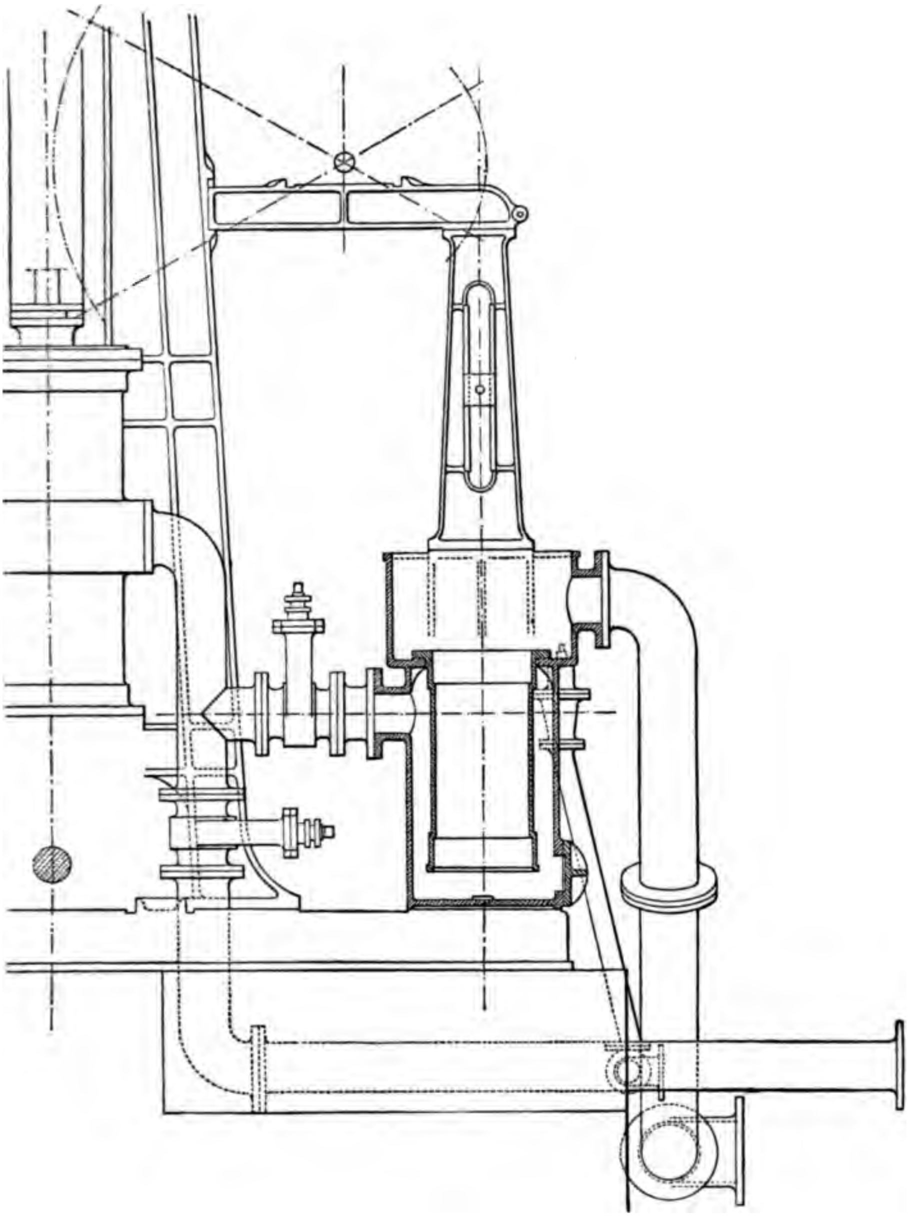


Fig. 731.—Daglish's Blowing Engine: Cylinder, Condenser, and Air-pump. Scale 1/32d.

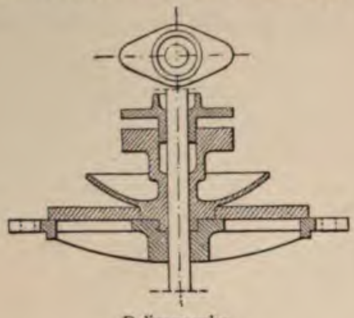
steel, 3½ inches in diameter, let into the piston with a taper, and fastened with a wrought-iron nut on the end, 2½ inches thick.

The crosshead, fig. 728, is of wrought iron, formed with a central eye to

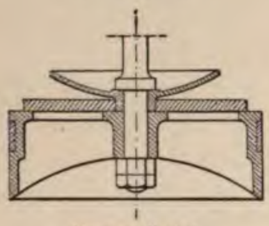
receive the piston-rods, two bosses finished with flat sliding surfaces to work in the vertical frames, and two journals, one at each end, to take a pair of connecting-rods to the main shaft below. The crosshead is 6 feet 1¼ inches long between the centres of the journals, 11½ inches by 2½ inches thick at the centre, 5 inches by 1½ inches at the ends. The central eye is 7¼ inches square, 17 inches deep; and it receives the ends of the upper and lower piston-rods, which are reduced to 3¼ inches in diameter, and are cottered into it. The end journals are 3½ inches in diameter, 4½ inches long; and the intermediate bosses are 5¼ inches thick, with sliding surfaces 4½ inches wide, 10 inches deep. The connecting-rods, one at each side, are 11 feet 5 inches long, or 12½ times the length of the crank, with end bearings formed with a butt, strap, gib and cotter, and brasses. They are round, 3½ inches in diameter at each end, swelled to 5 inches at the middle.

The main shaft is of wrought iron, 7 inches in diameter, turned, having two 6-inch journals 9 inches long. Two fly-wheels, 12¼ feet in diameter, 8 inches wide at the rim, are cast in halves, joined by bolts and hoops at the nave, and dowels and cotters at the rim. They are fastened on the shaft, one at each end, made with a crank-pin, having a 3-inch journal, 4½ inches long, to take the connecting-rod.

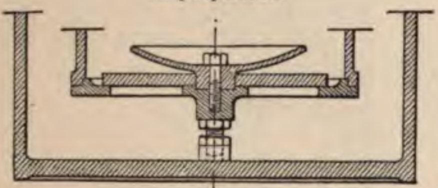
The steam-cylinders are each fitted with a main slide-valve of cast iron, having ⅞ inch of lap and 1/16 inch of lead, and two adjustable cut-off or expansion valves on the back of the main valve. The admission may be varied from ⅛th of the stroke to ⅞ths. The valve-spindles are of steel, respectively 1½ inches and 1¼ inches in diameter. The valves are worked by two eccentrics cast in one piece, of 5½ inches throw, one to each valve, of which the



Delivery-valve.



Air-pump Bucket.



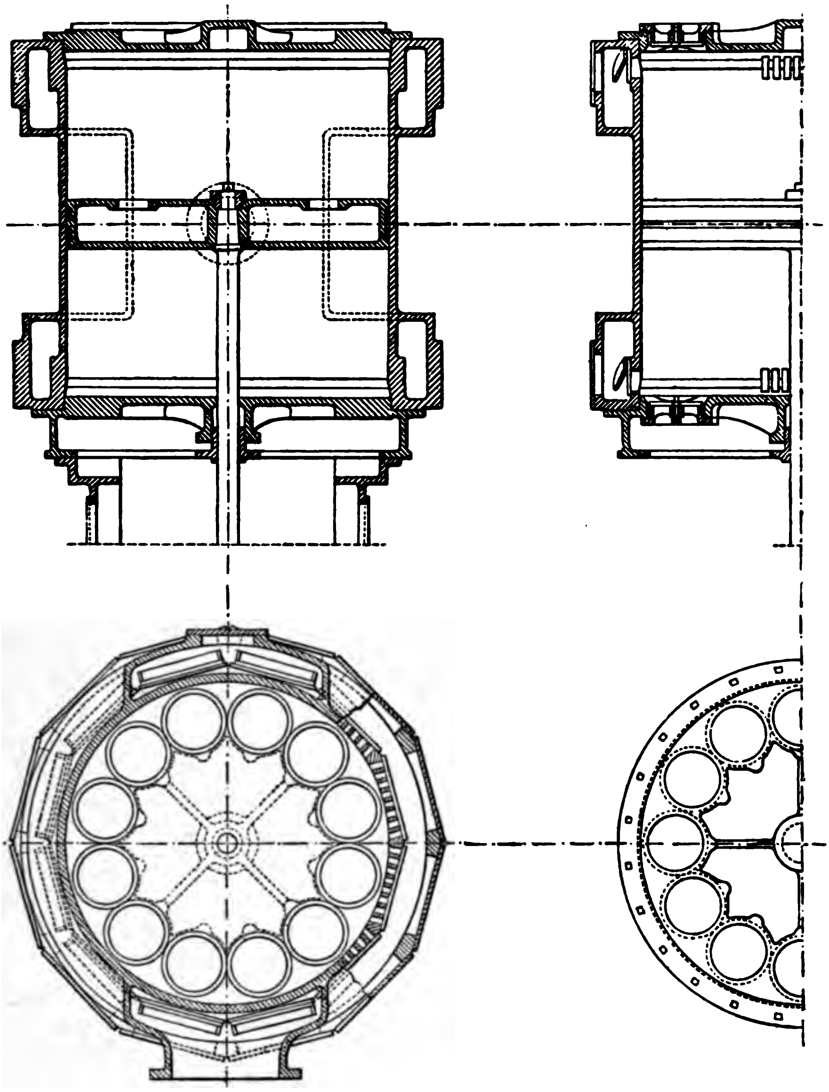
Bottom of Condenser and Air-pump Barrel. Section of Suction-valve.

Suction-valve Seat.

Figs. 732.—Daglish's Blowing Engine: Details of Air-pump. Scale 1/12th.

rods are pinned to the spindles. The eccentrics are keyed on a short shaft, 3¾ inches in diameter, driven by 18-inch mitre-wheels from the main shaft. A pulley is keyed on the end of this shaft, from which the governor is driven.

Steam is supplied to the pair of engines by a 9-inch cast-iron pipe,



Figs. 733.—Daglish's Blowing Engine: Blowing Cylinder. Sections. Scale 1/32d.

of ¾-inch metal, with a 6-inch branch-pipe and stop-valve to each engine, of ¾-inch metal. The exhaust steam is taken from the cylinder through a 7-inch cast-iron exhaust-pipe, of ⅝-inch metal, into the condenser, fig. 731, which is cylindrical, 2 feet in diameter, of cast iron, ¾ inch thick, except at the bottom, which is ⅞ inch. The air-pump, figs. 731 and 732,

is of ½-inch gun-metal, 16 inches in diameter, fitted concentrically into the condenser. It is fitted with a suction-valve and a delivery-valve of brass at the bottom and the top, of gridiron formation, with an india-rubber disc-valve to each, ¾ inch thick. The bottom valve is fastened in place simply by an adjustable screwed stud off the bottom of the condenser. The bucket is similarly constructed, with a 1⅝-inch phosphor-bronze rod, fastened to it by double-nuts. It is packed with a brass ring 2 inches wide, ⅜ inch thick. A wrought-iron crosshead is fastened by a nut on the upper end of the rod, and is guided by slides moving between upright guide-bars, fastened on the top of the hot-well. The air-pump has a stroke of 2 feet, or half the stroke of the steam-cylinder. It is worked by a motion off the steam crosshead, consisting of a reciprocating lever having arms as 2 to 1, connected to each crosshead by links. The lever is constructed of two ¾-inch wrought-iron plates, keyed 17 inches apart between centres on a 4¼-inch rocking shaft, linked to corresponding journals on the crossheads.

The injection-water is brought in a 3½-inch cast-iron pipe under the floor-line, branched into two 2½-inch pipes, one to each condenser, with a 2½-inch injection cock.

The waste water is carried off in two 8-inch cast-iron pipes of ⅝-inch metal, one from each hot-well, into a 10½-inch main under the floor-line.

When the steam is not condensed it is discharged direct from the cylinders into a 7-inch exhaust-pipe carried under the floor-line. The course of the steam—to the condenser or to the direct exhaust-pipe—is regulated by means of suitable shut-off valves.

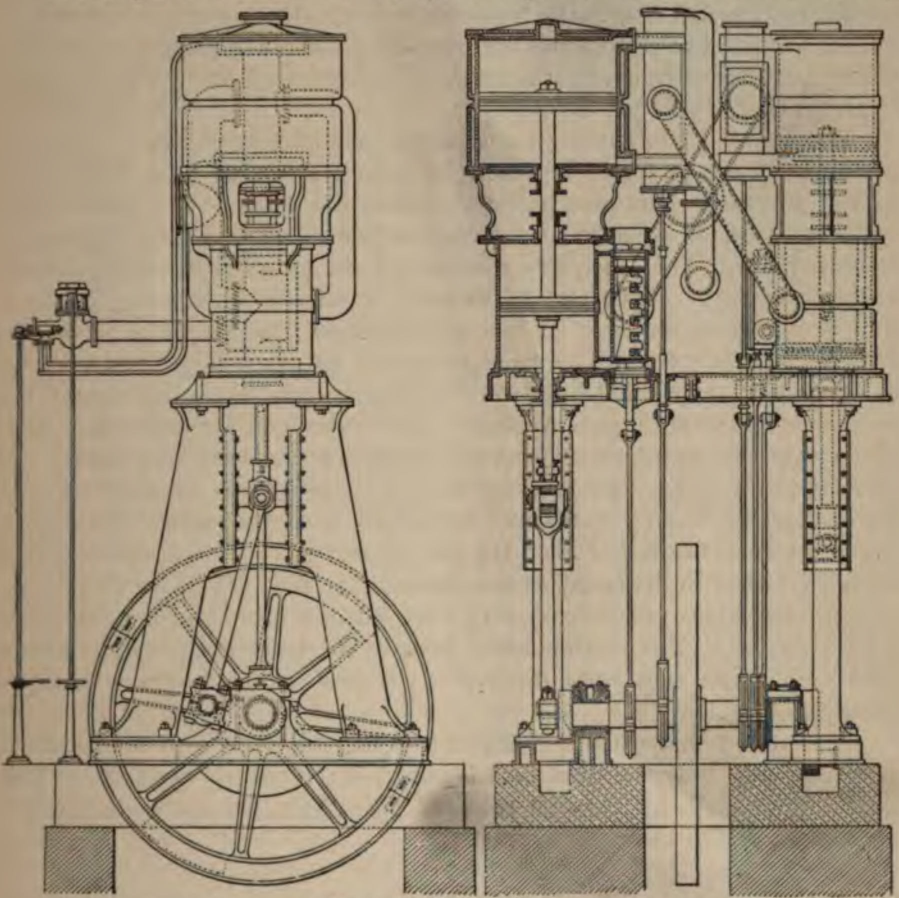
Each blowing cylinder, figs. 733, is of cast iron, 54 inches in diameter, with a stroke of 4 feet, of 1¼-inch metal. There is 1 inch of clearance between the piston and the cover at each end of the stroke, though ¾ inch would suffice. The covers are fastened to the cylinder with twenty-four ⅞-inch bolts and nuts for each, at about 7½ inches of pitch. Each cover is formed with twelve circular openings, 9½ inches in diameter, into each of which a circular gridiron-valve, figs. 734, 9 inches in diameter, is fixed, fitted with an india-rubber disc ¾ inch thick. These valves open inwards for the ingress of air to the cylinder from the top and the bottom alternately. The air received into the cylinder during each stroke is compressed to a pressure of 3 lbs. above the atmosphere during the alternate stroke, and is driven out of the cylinder through ninety-six openings 3½ inches by 1 inch at each end, distributed all round the cylinder. These openings are commanded by twelve india-rubber flap-valves at each end of the cylinder, opening into an annular chamber, 5 inches wide, 13½ inches high, from which the compresse ed and is passed off through an 18-inch cast-iron conduit etal into a receiver of wrought-iron plate, 3½ feet in h, whence it passes to the furnaces.

Figs. 734.—Daglish's Blowing Cylinder: Air-valve. Scale 1/12th.

Each engine is erected on a stone foundation 8 feet deep, 15 feet long, 4 feet 2 inches wide at the top, 2 feet longer and wider at the bottom. The base-plate is held down with ten 1½-inch holding-down bolts.

The engines are placed 11 feet apart between their centre-lines.

The engine-house is of brick, 27 feet square, with 21-inch walls, of a



Figs. 735.—Vertical Compound Blowing Steam Engine: Blaenavon Iron-works. Scale 1/108th.

total height of 39 feet 10½ inches from the bottom. Three floors are provided, with stairs, giving easy access to all parts of the engines.

The gross weight of the two engines complete, with connections within the engine-house, is 62 tons, including 83 cwts. for each fly-wheel, or 16 tons 12 cwts. for four fly-wheels. The price is £1580, or, say, £25, 10*s.* per ton.

VERTICAL COMPOUND BLOWING STEAM ENGINE FOR THE BLAENAVON IRON-WORKS.

(Cylinders 42 inches and 78 inches in diameter, stroke 60 inches.)

This blowing engine, figs. 735, was designed to be used in the process

of manufacturing Bessemer steel. The two steam-cylinders are connected direct by the piston-rods to two air-cylinders, and are placed vertically overhead in two tiers side by side, each of which comprises one steam-cylinder and one air-cylinder. The first steam-cylinder is below the air-cylinder, and the second steam-cylinder is above the air-cylinder; and the steam is exhausted diagonally from the first cylinder upwards to the second cylinder. The two piston-rods are connected to cranks placed at an angle of 225° with each other, on the ends of the fly-wheel shaft, which has its bearings on the base-plate.

The framing consists of two separate cast-iron base-plates, of hollow section, to each of which two upright members of cast iron, hollow, are bolted, on the top of which the cylinders are fixed. The first steam-cylinder is bolted down to the framing on one side, and an air-cylinder on the other side. The other air-cylinder and the second steam-cylinder are respectively fixed above and to these, by means of intervening castings. The first steam-cylinder is 42 inches in diameter; the second is 78 inches; with a stroke of 5 feet. The capacity ratio is 1 to 3.45. The first cylinder is fitted with expansion-slides on the back of the main slide, and the second cylinder with piston-valves. The cylinders are steam-jacketed; and steam can be admitted from the boiler into the second cylinder when starting the engine. The design of the engine comprises a separate engine for condensing, though it can also be worked non-condensing. The working pressure in the boiler is 90 lbs. per square inch. The air-cylinders are each 54 inches in diameter, with a stroke of 5 feet. They are fitted with piston inlet-valves, and several small wrought-iron automatic circular valves for the delivery. The air pressure is from 25 lbs. to 30 lbs. per square inch. The crank-shaft is of wrought iron, 14 inches in diameter, with journals 20 inches long.

It is stated that when this engine is doing full duty, with condensation of steam, only 168 pounds of coal is used per ton of steel produced. This consumption includes the coal required for driving the hydraulic engines for moving the Bessemer apparatus.

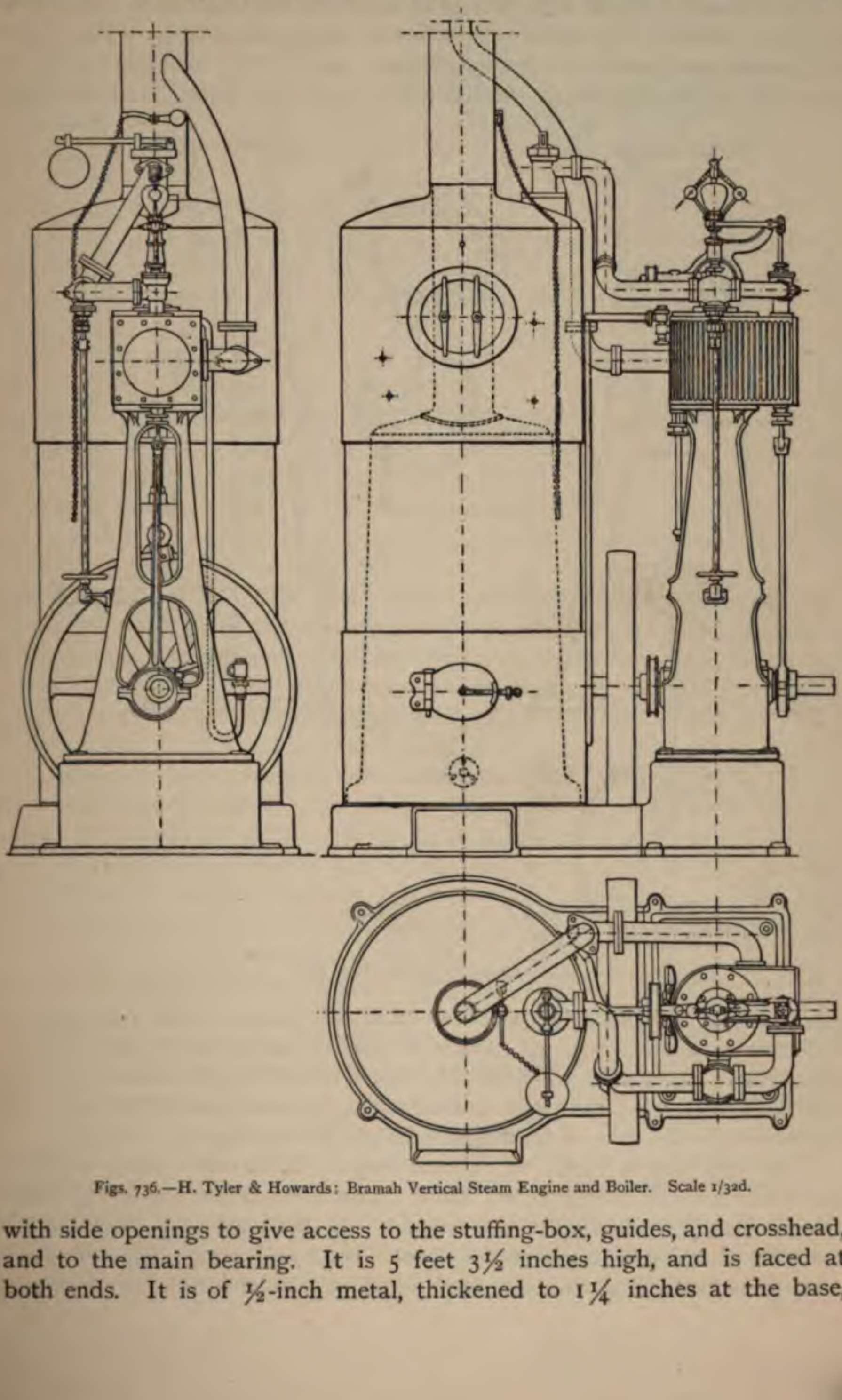
CHAPTER XLVI.—BRAMAH VERTICAL STEAM ENGINE AND BOILER, OF 10 HORSE-POWER.

CONSTRUCTED BY MESSRS. H. TYLER & HOWARDS, LUTON.

(Cylinder 10 inches in diameter, stroke 11 inches.)

In the Bramah vertical steam engine, figs. 736, the frame is in one compact upright casting with the guide-bars and the main bearing which is at the lower part. It is mounted on a cast-iron stool bedded on the foundation, and it carries the steam-cylinder on the top. The ruling form of the frame, as in figs. 737, is that of a truncated cone, slightly bell-

mouthed at the lower part. It is developed into a rectangular base, 33 inches by 21¼ inches; and it is 10½ inches in diameter at the top,

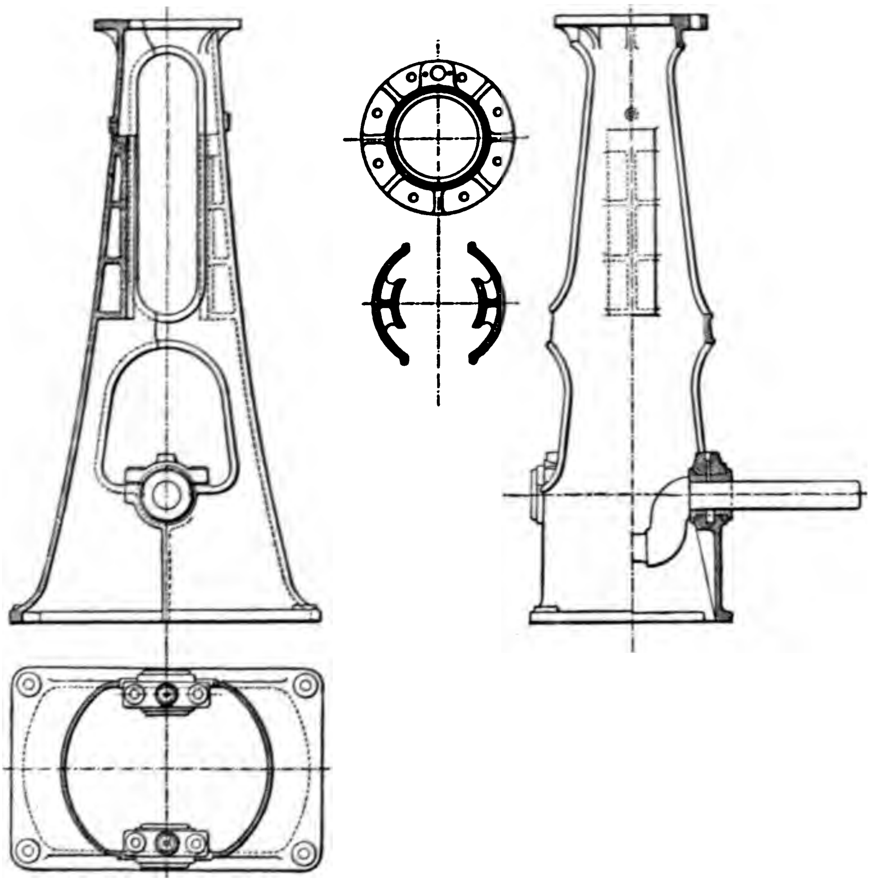


Figs. 736.—H. Tyler & Howards: Bramah Vertical Steam Engine and Boiler. Scale 1/32d.

with side openings to give access to the stuffing-box, guides, and crosshead, and to the main bearing. It is 5 feet 3½ inches high, and is faced at both ends. It is of ½-inch metal, thickened to 1¼ inches at the base,

and finished with a flange at the top, 1 inch thick and 15½ inches in diameter, to take the cylinder.

The steam-cylinder, figs. 738, is 10 inches in diameter, with a stroke of 11 inches, making 130 turns or 238 feet of piston per minute. The working steam pressure is 50 lbs. per square inch. The nominal power is reckoned at the rate of 10 circular inches per horse-power, and the indi-

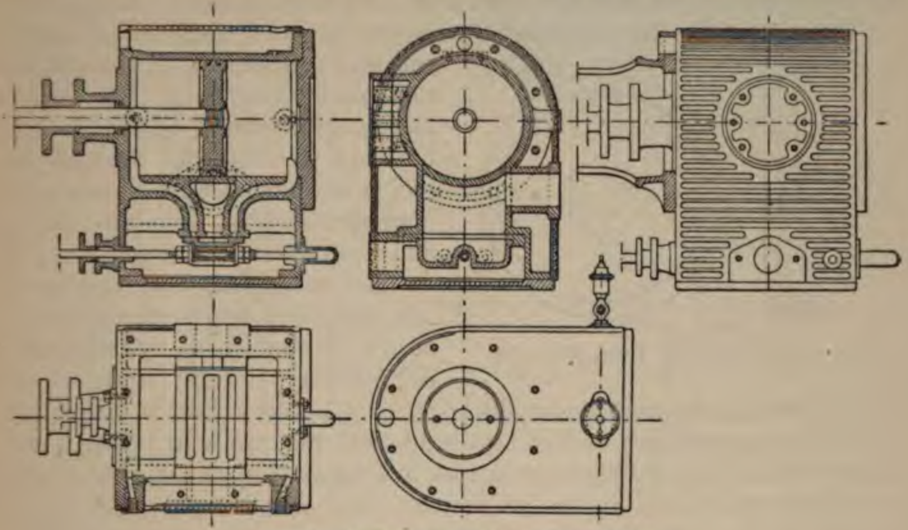


Figs. 737.—Bramah Engine: Frame and Main Shaft. Scale 1/20th.

cator power is taken as twice the nominal power. The low ratio of indicator power to nominal power is readily explained by the relative shortness of the stroke, which is only 1 inch more than the diameter. The shortness of stroke, and the correspondingly short connecting-rod, are expedient for the sake of limiting the height of the engine.

The cylinder is plain, of ⅝-inch metal. It is one casting with the lower cover, which is 1⅛ inches thick. The cove[illegible] top is 1¼ inches thick. The joint flanges of the cylinder ar [illegible] ⅞ inch thick, and they are fastened with eight ¾-inc[illegible] cylinder is of sufficient clear length inside to allo[illegible] each

end. The valve-chest is of ½-inch metal, and is of the same length externally as the cylinder. The steam-passages come together in ordinary three-ported valve-face. The steam-ports are ⅝ inch by 7¼ inches; but



Figs. 738.—Bramah Engine: Cylinder. Scale 1/16th.

the passages are ¾ inch wide. The exhaust-port is 1¼ inches by 7¼ inches. The areas of the ports are respectively $^1/_{17.3}$ part and $^1/_{8.6}$ part of the area of the cylinder. The valve-face is recessed to form ledges or guides, between which the valve travels. There is a single valve of cast iron, $^7/_{16}$ inch thick. It has ⅝ inch of lap at each end, and ⅛ inch lead; and it is worked by a single eccentric, having a travel of 2¼ inches, cutting off at half stroke. The valve-spindle is of mild steel, ¾ inch in diameter. It traverses the valve, which is recessed to make room for it, and is held between two pairs of nuts on the spindle. The nuts are screwed up tight on a piece of mild-steel tube threaded by the spindle, by which the nuts are prevented from binding the valve. The spindle is extended upwards at ⅝ inch in diameter, to be guided by a socket in the lower part of the throttle-valve seat, in which it reciprocates; and it passes through a stuffing-box at the lower side of the chest, outside of which it is pinned to the eccentric-rod. The cover of the valve-chest is ½ inch thick, and it is fastened to the chest with ¾-inch flanges and twelve ⅝-inch stud-bolts and nuts. Steam from the boiler is brought into the valve-chest by a 2½-inch wrought-iron pipe, fitted

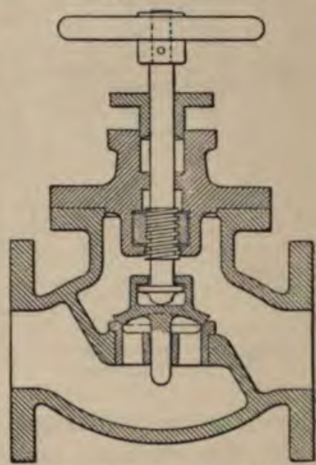
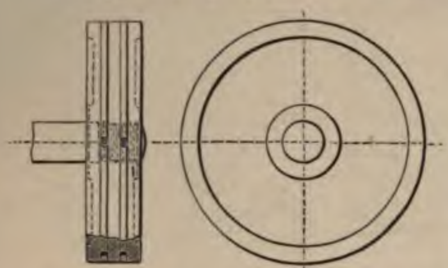


Fig. 739.—Bramah Engine: 2½-inch Steam Stop-valve. Scale 1/6th.

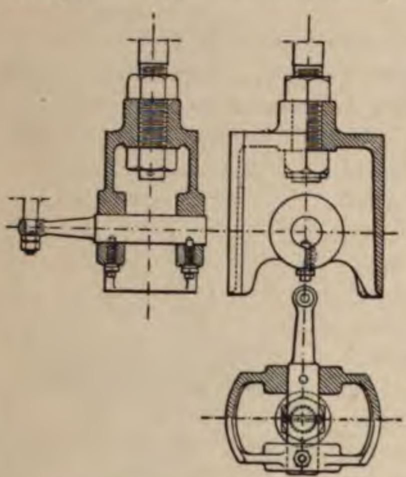
with a steam stop-valve, fig. 739, worked by a hand-wheel below, and a throttle-valve controlled by the governor. The exhaust steam is taken off by a 3-inch pipe to the chimney. The cylinder and the valve-chest are well encased with silicate cotton, with a cast-iron covering.

The piston, figs. 740, is a solid disc of cast iron, 2¼ inches thick at the rim, and panelled. It is grooved for two packing rings, each ¼ inch wide and 5/16 inch thick, of steel. The nave is 2 inches thick. The piston-rod is of mild steel, 1⅝ inches in diameter, screwed into the piston, and riveted over at the end.



Figs. 740.—Bramah Engine: Piston. Scale 1/8th.

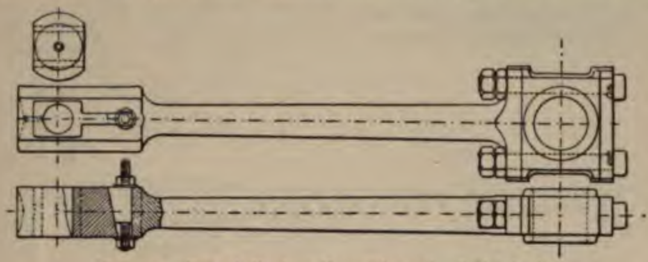
The crosshead, figs. 741, is of cast iron, of a box form, open only at the bottom to receive the connecting-rod. It is 8½ inches wide between the guides, and has a thickness of 5 inches. This is the width of the sliding surfaces of the crosshead, and they are 8⅞ inches long. These surfaces and those of the guides are respectively turned and bored to a diameter of 8½ inches to match. The metal is 7/16 inch thick, except the top, which is made ¾ inch thick to receive the piston-rod. The rod is reduced to 1½ inches in diameter, passed through an eye on the crosshead, which is secured to the rod by two nuts, 1¼ inches thick, one inside and one outside, and a safety-pin through the end. The crosshead pin is of steel. It is a plain cylinder 1⅝ inches in diameter, fixed in each of the side bearings of the crosshead, which are 2¾ inches apart and 1½ inches thick, by a ½-inch set-screw, with a jam collar-nut. It is extended at one side to take the head of the pump-ram, which is worked from it.



Figs. 741.—Bramah Engine: Crosshead. Scale 1/10th.

The connecting-rod, figs. 742, is of wrought iron, 27½ inches in length, or five times the length of the crank. The body is round, uniformly tapered from 2 inches in diameter at the crank end to 1⅝ inches at the crosshead end. The crosshead end is solid forged, 2¾ inches thick, and 3¾ inches wide. It is slotted out to receive the brasses, which are rectangular externally, flush with the sides of the piece, 7/16 [illegible] bove and below the journal; and giving a bearing 1⅝ i[illegible], 2¾ inches in length. The lower brass has a pin, which [illegible] sponding slot, and takes the pressure of the cotter, [illegible] hick,

2 inches long, lodged within the metal, screwed at each end, ½ inch in diameter, and secured by a collar-nut, ⅝ inch thick, bearing on each face. The wedge tapers 5/16 inch, or at the rate of about 1 in 6. Lubrication is provided for by scooping out the top of the rod, to form a shallow reservoir of oil, from which a small oil-passage is drilled. The crank end is on the cap-and-bolts system, in which the brasses are formed with square



Figs. 742.—Bramah Engine: Connecting-rod. Scale 1/10th.

backs, and are held between a flat palm, ⅞ inch thick, on the end of the rod, and a cap ¾ inch thick, each of them 6¼ inches by 2⅝ inches, with two ⅞-inch turned bolts and double-nuts, 4¼ inches apart. Under each bolt-head a stop-pin is screwed into the bolt, the head of which is let into a slot in the cap to prevent the bolt from turning. The brasses are ⅝ inch thick at the top and bottom, and they give a bearing 3 inches in diameter by 3 inches long.

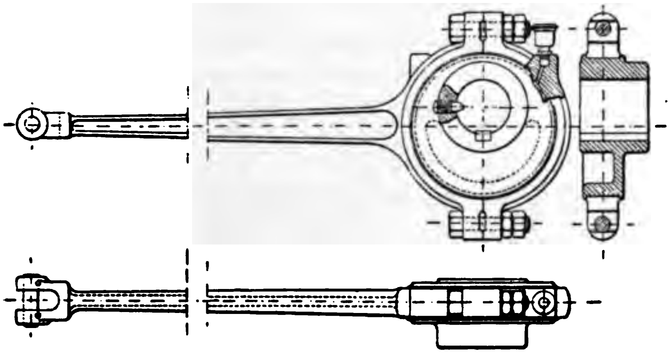
The main shaft, partly shown in figs. 737, is of wrought iron, bent to form a double-arm crank of 5½-inch radius. It is turned to a diameter of 3 inches at the straight portions and at the crank-pin. The crank-arms are 3½ inches in diameter. The journals are each 3 inches by 4½ inches long, and they are 16½ inches apart between centres. The fly-wheel, figs. 743, is of cast iron, in one piece, 4 feet in diameter. The rim is 4½ inches deep radially, and 3 inches thick, widened to 5 inches at the circumference, and turned. The nave is 6 inches in diameter, giving 1½ inches of metal round the shaft, and 5 inches wide. There are six arms, oval in section, 3⅛ inches by 1¾ inches at the nave, tapered to 2¼ inches by 1⅜ inches at the rim. The wheel is fixed on the shaft with a steel key.

Figs. 743.—Bramah Engine: Fly-wheel. Scale 1/16th.

The main bearings, figs. 737, are 3 inches in diameter and 4½ inches long, 12 inches apart in the clear; in one with the frame. The brasses are of hard gun-metal, ⅝ inch thick, cylindrical externally, and prevented from turning in their seats by gun-metal pins through the bottom brasses. The cap is of cast iron, let in between the sides of the bearings, and fastened with two ⅞-inch stud-bolts and nuts.

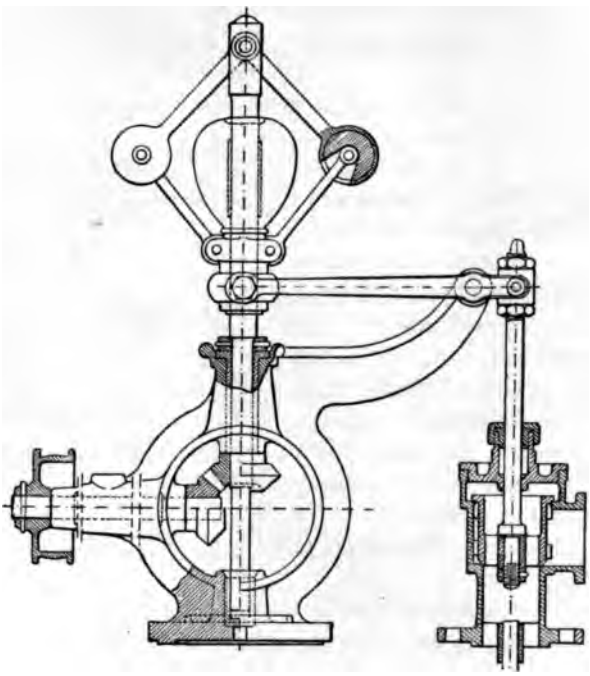
The eccentric, figs. 744, for working the slide-valve is of cast iron, in one

piece, 7½ inches in diameter and 2¼ inches wide, grooved 1¾ inches wide, for the strap. It has 1⅛ inches of eccentricity, or 2¼ inches of throw. The nave is 3¾ inches wide, and 15/16 inch thick round the shaft;



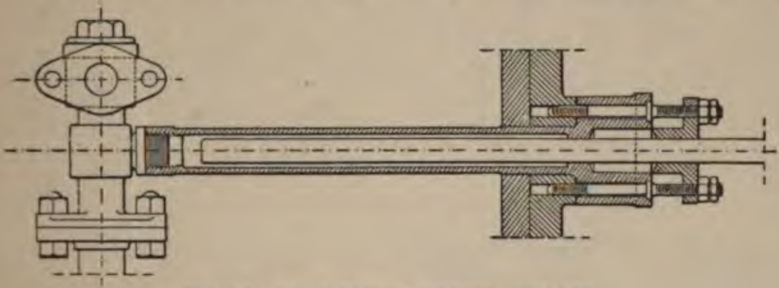
Figs. 744.—Bramah Engine: Eccentric and Rod. Scale 1/10th.

and is bored to fit the shaft, on which the eccentric is fixed with a steel key ¾ inch by ½ inch, let ⅛ inch into the shaft. The nave is made wide in order to prevent the eccentric being driven out of truth by the key. The eccentric is secured also by a ⅝-inch set-screw to secure the eccentric sidewise, the shaft not having any journals. The set-screw is turned by means of a screw-driver. The strap is of malleable cast iron, 1 inch thick, in halves, bolted together with 1⅛-inch flanges and two ¾-inch bolts and double-nuts. The rod is one piece with a half-strap, and is 3 feet 8 inches in length between centres. It is forked to take the valve-spindle with a ¾-inch pin, having a bearing 1⅛ inches long in the eye of the spindle, and ¾ inch in each fork. The pin is a simple cylinder, and is fixed into the forks with two 3/16-inch pins. The eccentric-rod is of H section. It has a ½-inch web, and ¼-inch upper and lower flanges; it is 2 inches by 1⅜ inches at the strap, and 1 inch by 1 inch at the other end.



Figs. 745.—Bramah Engine: Governor. Scale 1/8th.

The governor, figs. 745, is of the Porter type, similar to the one already noticed for the horizontal engine, page 135. It has 2½-inch balls on 6½-inch arms, moving at quick speed, and a central weight 4½ inches in diameter. The spindle is of steel, 1⅛ inches in diameter at the upper part, reduced to 1 inch in the bearing, which is 4⅜ inches long. A collar is pinned on the spindle to take the weight, and works on the bearing. The lower part of the spindle is ⅞ inch in diameter, and runs in a footstep. The frame, of which the bearing and footstep form parts, is of cast iron, and carries a pair



Figs. 746.—Bramah Engine: Feed-pump. Scale 1/6th.

of mitre wheels through which the governor is driven from a 4½-inch pulley on a horizontal shaft, driven by a band from a 9-inch pulley on the main shaft. The speed of the governor is thus made double the speed of the engine, or 260 revolutions per minute, at normal speed. The governor acts upon an equilibrium throttle-valve, of gun-metal, having two conical discs and seats, 2½ inches in diameter at the lower seat and 3½ inches at the upper seat. The body of the valve and the casing are $3/_{16}$ inch thick. The casing is closed at the top by a cover screwed into it, with a stuffing-box, through which the ¾-inch spindle works. The lower part of the valve-seat is fitted as a guide for the spindle of the cylinder slide-valve. The throttle-valve is bolted to the valve-chest, and has a 2½-inch entrance for steam from the boiler. It is controlled by the governor through a lever having arms in the ratio of 5.2 to 1, pinned to a sleeve on the governor spindle, which rises and falls with the weight.

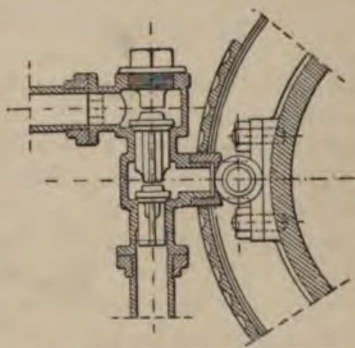
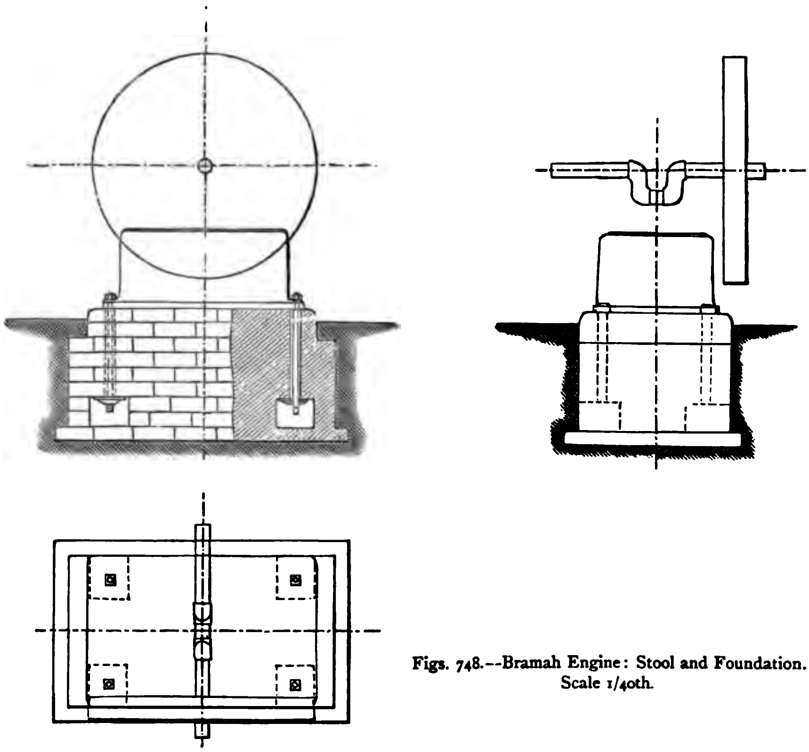


Fig. 747.—Bramah Engine: Feed-delivery Valve. Scale 1/6th.

The feed-pump, fig. 746, is of gun-metal, of mild quality. It is single-acting, and is worked direct from the crosshead, with a stroke of 11 inches. It is fixed vertically to the side of the cylinder and the top of the frame. The ram is of mild steel, $^{13}/_{16}$ inch in diameter, working in a barrel $1^{1}/_{16}$ inches in diameter inside, and $3/_{16}$ inch thick. The suction and delivery pipes are of 1-inch gas tube. The valves, fig. 747, are three-leaved, and conical, and are lodged in a casing at the upper end of the pump. The suction-valve is ⅞ inch in

diameter, with a little less than $\frac{1}{8}$ inch of lift; the delivery-valve is $1\frac{1}{8}$ inches in diameter, and has $\frac{1}{8}$ inch lift.

The engine is fixed on a cast-iron base or stool, figs. 748, of $\frac{1}{2}$-inch metal, with thickened edges, 17 inches high, with four $1\frac{1}{8}$-inch corner bolts and nuts. The stool is placed on a foundation of brickwork, 5 feet 3 inches long by 3 feet 2 inches at the base, 4 feet $\frac{3}{4}$ inch by 2 feet 9 inches at the



Figs. 748.—Bramah Engine: Stool and Foundation.
Scale 1/40th.

top, and 2 feet $4\frac{1}{4}$ inches deep. The stool is fastened by four $1\frac{1}{8}$-inch holding-down bolts, with plates, cotters, and nuts. Four recesses in the brickwork are made to receive the plates.

The weight of the Bramah vertical engine described is $23\frac{1}{2}$ cwts., which includes $6\frac{1}{2}$ cwts., the weight of the fly-wheel, and 5 cwts. 1 qr. 20 lbs., the weight of the frame. The stool or cast-iron foundation, in addition, weighs 1 cwt. 2 qrs. The price of the engine is £75, or about £64 per ton. The price of the cast-iron stool, with bolts and nuts, is £4, 12*s.*, and that of bolts and plates for the foundation is £1, 10*s.*

On the next page are given a few particulars of vertical Bramah steam engines of from 3 to 10 nominal horse-power.

The steam boiler from which steam is obtained for working the 10-horse-power engine is shown in figs. 736, page 379. It is vertical, $3\frac{1}{2}$ feet in diameter and 9 feet high, and it stands on a cast-iron base 9 inches high. The fire-box is 5 feet 9 inches high, and it tapers slightly to a diameter of

Vertical Bramah Steam Engines, by H. Tyler & Howards.

NOMINAL HORSE-POWER	3.	4.	6.	8.	10.
Diameter of cylinder............inches	5¼	6½	8	9	10
Stroke of do. .... „	8	8	9	10	11
Diameter of fly-wheel .... „	33	36	42	45	48
Width of do. at rim... „	3¼	3½	4	4½	5
Speed in turns per minute ......turns	180	180	160	144	130
Do. of piston in feet per minute..ft.	240	240	240	240	238
Diameter of steam-pipe ....ins.	1¼	1½	2	2	2½
Do. exhaust-pipe.......... „	2	2	2½	2½	3
Do. feed-pipes .... „	¾	¾	1	1	1
Length over all....................ft. ins.	2 9	3 0	3 6	3 9	4 0
Width do. .... „	2 6	2 6	2 10	3 0	3 9
Height do. .... „	6 0	6 0	7 0	7 10	9 0
Weight of engine....................cwts.	7	8½	12½	15	23½
Do. stool.................... „					1½
Do. engine packed......... „	8½	10	14½	17½	27

2 feet 8 inches, outside, at the crown. There are four 9-inch cross-tubes. The uptake is 10 inches in diameter outside, connecting the crown of the fire-box to the crown of the shell—which are about 3 feet 3 inches apart. The grate-area is 9 square feet; the heating surface is 100 square feet. Steam for the engine is taken through the safety-valve casting on the crown of the shell, and the exhaust steam is discharged into the chimney. A damper in the chimney is regulated by means of a chain. The boiler weighs 37 cwts.

The cast-iron base, embracing engine and boiler together, weighs 6 cwts.

CHAPTER XLVII.—OVERHEAD WALL STEAM ENGINE.

CONSTRUCTED BY MESSRS. J. COPELAND & CO., GLASGOW, FOR THE CLYDE LOCOMOTIVE COMPANY.

(Cylinder 16 inches in diameter, stroke 20 inches.)

The overhead wall steam engine is specially adapted for driving a line of shafting directly—the engine being connected to the shaft without intermediate communications.

Messrs. Copeland & Co. have supplied seven wall engines to the Clyde Locomotive Works, placed as follows:—

	Number of Engines.	Speed in Turns per Minute.
Heavy tool shop..	1	90
Light tool shop..	2	120
Boiler shop..	1	120
Grinding shop..	1	120
Smith's shop and scrap shed..........................	1	120
Engines with 16-inch cylinders............	6	
Pattern shop, 14-inch cylinder........................	1	120
Total number of engines............	7	

Each engine drives a line of shafting coupled direct to the end of the crank-shaft of the engine. The lengths of the lines of shafting vary from 180 feet to 80 feet; the diameters of the shafting diminishing by stages, from 4½ inches to 4 inches, 3½ inches, and 3 inches.

There are 1500 feet of shafting to be driven, all of Siemens mild steel, supported by 170 hangers, with 450 driving pulleys of from 52 inches to 12 inches in diameter. The hangers have split cast-iron bearings having means of vertical adjustment to take up wear by means of screws which act on a spherical-faced plug, and capable of swivelling to allow for any deviation in working. This kind of bearing is less costly and lasts much longer than ordinary wall-bracket and plummer-block bearings.

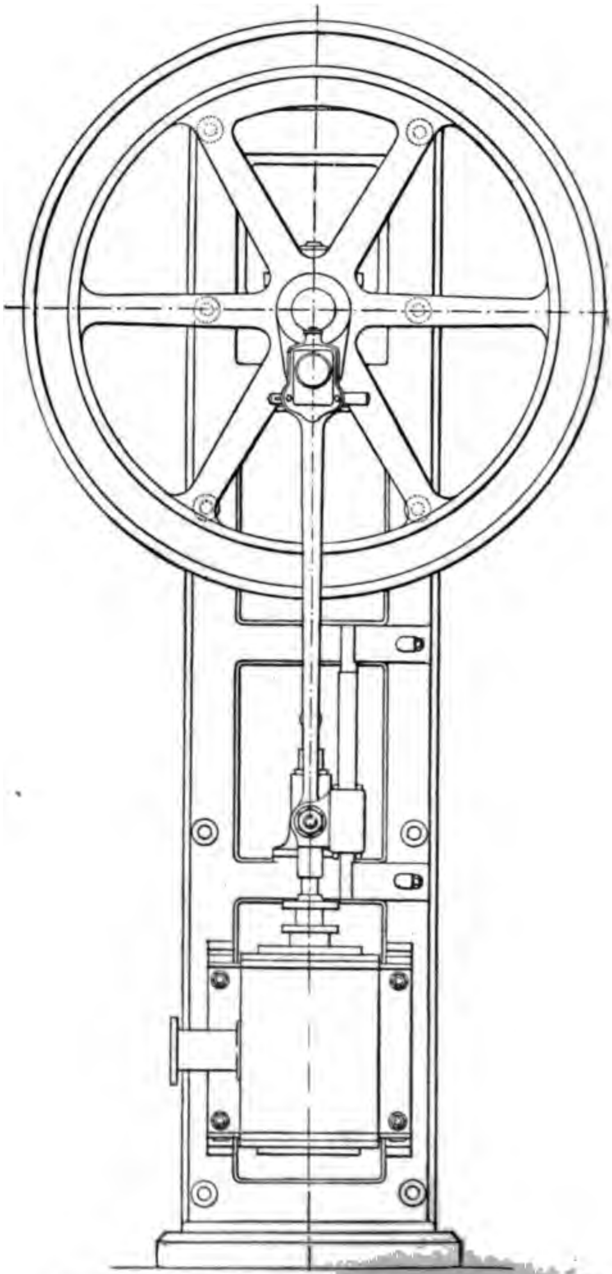
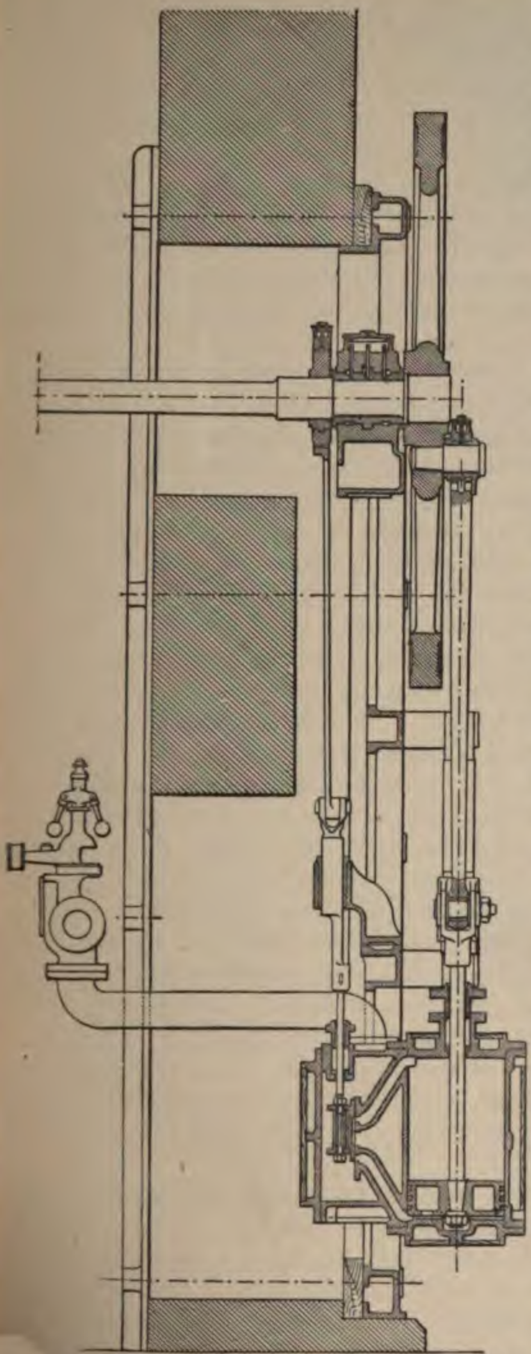


Fig. 749.—Overhead Wall Engine, by Messrs. J. Copeland & Co
Eleva[illegible]

The advantages of the separate or independent system of engine-power, thus exemplified, amongst others, that in the event of any particular tool or machine being run during the night, or other tools being laid off work, only the line of shafting with which the tool is worked need be driven down all the tools and machines need not



*. 750.—Overhead Wall Engine, by Messrs. J. Copeland & Co.: Vertical Section. Scale 1/32d.

The engine, figs. 749 and 750, as its name imports, is vertical, having a wall-plate or frame bolted to the wall, carrying the cylinder at the lower part, and the crank-shaft bearing at the upper part. The shaft is thus supported, and is passed through the wall unconnected with any wall-box. The crank-shaft is 13¼ feet above the ground-level, and the centre-line of the cylinder is 27½ inches from the face of the wall.

The frame is rectangular, 15 feet 7¼ inches long, 3½ feet wide, 6 inches deep. It consists of two sides 9 inches wide at the outer surface, and five transverse ties, hollow, of ¾-inch metal in the sides, 1¼ inches in the face. The bearing for the crank-shaft is cast on it, and also the brackets for carrying the guide-bars.

The cylinder is 16 inches in diameter, with a stroke of 20 inches, and a clearance of ½ inch between the piston and the cylinder-covers, at each end; of 1-inch metal. The cylinder-covers are 1⅛ inches thick, fastened each with ten ⅞-inch bolts and nuts, at about 3¼ inches of pitch. The valve-chest is of ⅞-inch metal, and its cover is 1 inch thick. The cylinder is fastened to the frame with two wing flanges, 1½ inches thick, and four 1⅛-inch bolts and nuts. The flanges are, in addition, keyed between snugs to the frame. The steam-ports inches by 1¼ inches, the exhaust-port is 11 inches by 2½ inches,

being respectively $^1/_{14.7}$ part and $^1/_{7.3}$ part of the piston-area. The steam is distributed by an ordinary slide-valve of cast iron, driven direct by a 14-inch eccentric on the crank-shaft; the valve having $1\frac{1}{4}$ inches of lap outside, $^1/_{16}$ inch lap inside, lead $^3/_{32}$ inch, and $4\frac{1}{2}$ inches of travel; cutting off at 68 per cent of the stroke.

The working pressure of steam in the boiler is 80 lbs. per square inch. The steam-pipe is of cast iron, 4 inches in diameter; it introduces the steam at the top of the valve-chest. The governor, combined with the stop-valve, is Tangye's electric governor. It makes 250 turns per minute. The exhaust-pipe is 5 inches in diameter, of a length varying from 20 feet to 30 feet.

There is a single guide-bar of mild steel, $5\frac{1}{2}$ inches wide, 3 inches thick, let into and bolted to two brackets cast on the frame.

The piston is of cast iron, in one piece, hollow, 6 inches thick, of $\frac{3}{4}$-inch metal, $1\frac{1}{2}$ inches thick at the rim, having three packing-rings of $\frac{1}{2}$-inch square cast iron, sprung into place. The rings were turned to $\frac{3}{8}$ inch larger diameter than the piston, then cut obliquely, and sprung into their places. The piston-rod is of Siemens mild steel, $2\frac{1}{2}$ inches in diameter, let into and through the piston with a taper $3\frac{1}{4}$ inches and $2\frac{1}{4}$ inches in diameter, or 1 inch in a length of 5 inches, fastened with a nut $2\frac{1}{2}$ inches thick.

The crosshead is of crucible cast steel, cast in one with the slide. The socket for the piston-rod is 6 inches deep, $4\frac{1}{4}$ inches in diameter outside, bored taper, from $2\frac{3}{8}$ inches to 2 inches. It is fastened on the end of the piston-rod with a steel cotter, and is forked to receive the connecting-rod. The gudgeon offers a journal $2\frac{3}{4}$ inches in diameter, $3\frac{1}{2}$ inches long, and is let into each side of the fork, with a taper, and fastened with a nut on one end. The slide is cast as a sleeve to embrace the guide-bar, $10\frac{1}{2}$ inches long, with a brass liner above and one below the bar.

The connecting-rod is a solid forging of Siemens mild steel, $6\frac{1}{4}$ feet long, or $7\frac{1}{2}$ times the length of the crank. The bearing at the crosshead end is $2\frac{3}{4}$ inches in diameter, $3\frac{1}{2}$ inches long, bushed with brass. The bearing for the crank end is $4\frac{1}{2}$ inches in diameter, 6 inches long. The brasses are halves, tightened by a cotter $1\frac{1}{8}$ inches thick, which acts on a bearing piece of steel at the back of the brass. An oil-cup is formed solid on the top of the connecting-rod. The body of the connecting-rod is round, uniformly tapered from $3\frac{1}{2}$ inches in diameter at the larger end to $2\frac{1}{2}$ inches at the smaller end.

The crank-shaft is a mild steel forging, $5\frac{1}{2}$ inches in diameter in the body, 7 inches for the eccentric, 6 inches for the journal, which is 12 inches long, 8 inches in the fly-wheel, and $7\frac{1}{2}$ inches long, comprising a fillet $\frac{1}{2}$ inch thick. The fly-wheel is of cast iron, in one piece, 8 feet in diameter, having six radial arms, oval in section, 6 inches by $3\frac{1}{2}$ inches, tapered to $4\frac{3}{4}$ inches by 3 inches; and a rim 5 inches wide by 9 inches deep, panelled or indented $\frac{1}{4}$ inch at each side. The centre is bored out to a diameter of 8 inches to fit the shaft, on which it is forced by [illegible] of screws, and fastened with one steel key 2 inches by 1 inch. [illegible]ht is cast

on the rim between two of the arms, so proportioned as to balance the weight of one-half of all the moving parts connected to the crank-pin. The crank-pin is of steel, having a 4½-inch journal, 6 inches long, let into a boss on the fly-wheel centre, which is shrunk on it with a slight taper; and it is riveted over.

The bearing for the crank-shaft, cast on the frame, has two brass bushes 1¼ inches thick above and below the journal, ⅝ inch at each side. It is closed with a cast-iron cap, and two 1½-inch bolts and double-nuts.

The eccentric for working the slide-valve is in two pieces, the larger of cast iron and the smaller of wrought iron, united on the crank-shaft by two 1¼-inch bolts, screwed and cottered, bored out to 7 inches in diameter, and turned to 14 inches; and 3 inches wide; and fastened with a steel key sunk into the eccentric. The strap is of cast iron, in halves joined with two long 1¹/₁₆-inch bolts and double-nuts; having an oil-cup cast on the top. The eccentric-rod is of wrought iron, united to the strap with a palm joggled to the strap, and two 1-inch screw-bolts and nuts. It is 5 feet 9½ inches long between centres, case-hardened at the eye on the lower end. The valve-spindle is of steel, 1½ inches in diameter, having an upper member cottered to it, thickened to a diameter of 4 inches, which works in a guide bushed with brass, 8½ inches long, bolted to the frame.

The frame-plate is bedded on oak and fastened to the wall with ten 1½-inch holding bolts and nuts, and two long cast-iron wall-plates at the back of the wall. These are of T section, 8 inches wide by 4 inches, of 1-inch metal.

Steam for the engines is supplied from a set of boilers which supply all the steam for steam hammers, &c. The main steam-pipe is overhead. It is 14 inches in diameter, and is reduced to 10 inches, 8 inches, 6 inches, and 4 inches. They are coated with fossil meal. The steam condensed in the pipes is collected in receptacles, one at each engine, fitted with a gauge-glass; and blown out at intervals by the attendant.

The gross weight of the engine, complete with wall-plates, is about 6½ tons, which includes 36½ cwts. for the fly-wheel, 32 cwts. for the sole-plate or frame-plate, and 11¼ cwts. for the wall-plates.

The price of the engine delivered is £183, or £28 per ton.

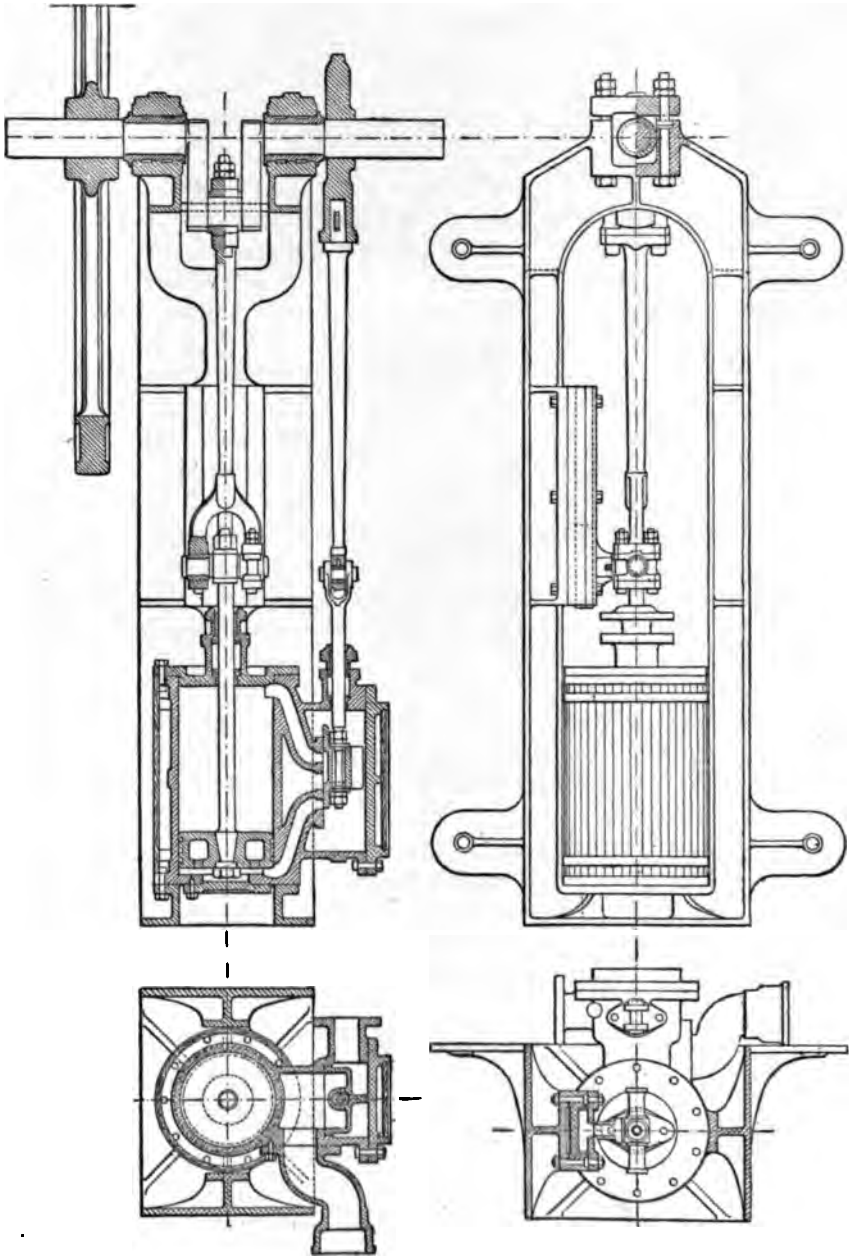
OVERHEAD WALL STEAM ENGINE (SECOND DESIGN).

CONSTRUCTED BY MESSRS. J. COPELAND & CO., GLASGOW.

(Cylinder 12 inches in diameter, stroke 18 inches.)

This wall engine, figs. 751, differs from the one just noticed in having the bed-frame or sole built into the wall. The cylinder is 12 inches in diameter, with 18 inches of stroke; of 1-inch metal. The wall is 22 inches thick, and the opening in it is 2 feet 4½ inches wide, and is occupied by the cylinder, which is placed vertically and centrally within the wall; and by the frame-plates, of 1-inch metal, one at each side of the opening. The centre of the crank-shaft is 8¼ feet above the level of the floor. The shaft

is 4¾ inches in diameter, and is double-cranked to take the connecting-rod. The connecting-rod is 3¾ feet long, or 4.33 times the length of the crank;



Figs. 751.—Overhead Wall Steam Engine, by Messrs. J. Copeland & Co., Glasgow. Scale 1/24th.

it is forked to take the two journals of the crosshead, and the bearings are each made with a cap and two bolts. The fly-wheel is 7 feet in diameter.

The cylinder is worked with an ordinary slide-valve, having 1¾ inches of outside lap, $^1/_{16}$ inch of inside lap, $^1/_{16}$ inch lead, and 5 inches of travel. There is ½ inch clearance between the piston and the cylinder at the top, and ¾ inch at the bottom. A slipper-slide is cottered to the back of the crosshead, and it slides between two pairs of guide-bars.

PORTABLE STEAM ENGINES.

CHAPTER XLVIII.

PORTABLE STEAM ENGINE OF 8 HORSE-POWER.

(Cylinder 10 inches in diameter, stroke 13 inches.)

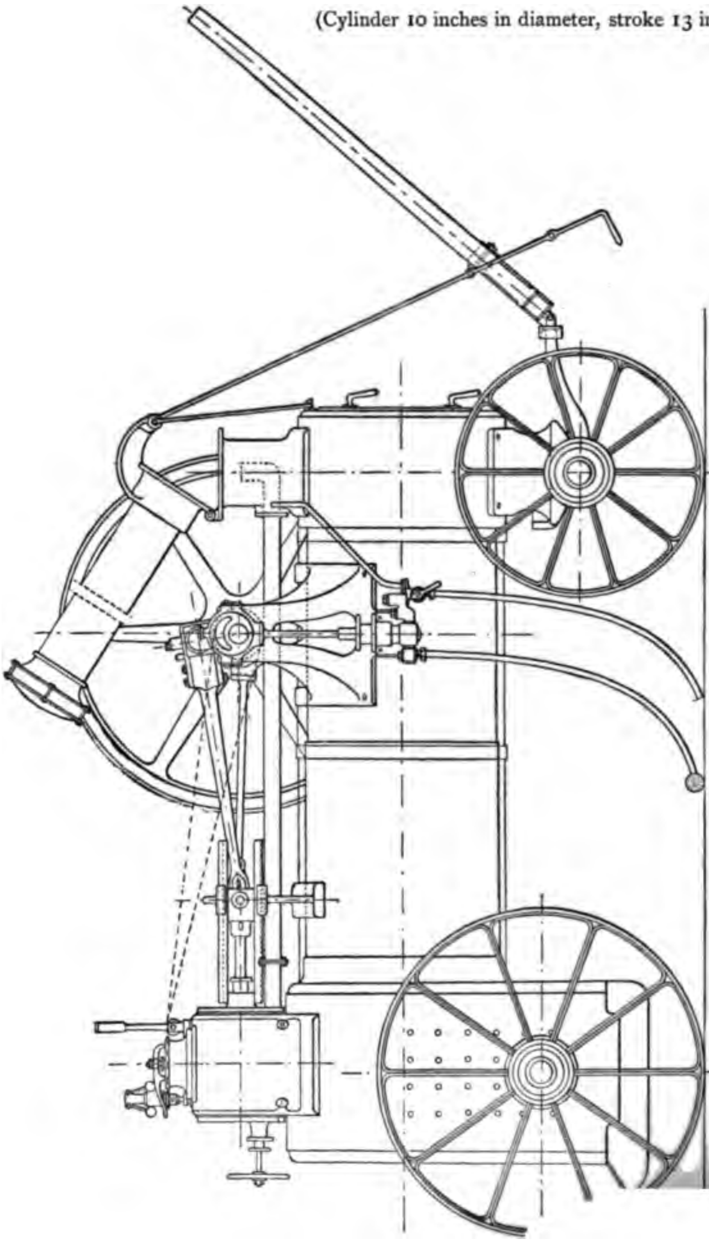


Fig. 752.—Portable Steam Engine: Longitudinal Elevation. Scale 1/32d.

This engine, illustrated by figs. 752, 753, and

multitubular boiler, surmounted by a single-cylinder engine, and supported on two pairs of wheels. The cylinder is 10 inches in diameter, with a stroke of 13 inches, and the working pressure is 80 lbs. per square inch in the boiler. The engine makes 128 revolutions per minute, or a speed of piston of 277⅓ feet per minute; and is capable of yielding, under ordinary conditions, 20 indicator horse-power; or even, on an emergency, 30 horse-power.

The Boiler.—The boiler, shown in detail in figs. 755, consists of a rectangular fire-box and horizontal flue-tubes, encased in a firebox-shell and a barrel or cylindrical inclosure, with a smoke-box and chimney at the other end of the barrel. The plates of which the boiler is constructed, including those for the smoke-box, chimney, and ash-pan, are of Siemens steel, of the ultimate tensile strength 27 tons per square inch. The plates of the fire-box and its shell are ⅜ inch thick, those of the barrel are 5/16 inch, and those of the smoke-box 3/16 inch, excepting the two tube-plates, which are 9/16 inch thick. The fire-box is 2 feet 8½ inches wide, and 1 foot 11¾ inches long; falling in upwards by half an inch at each side, to a width of 2 feet 7½ inches at the top. It is 2 feet 11½ inches high inside, but the height above the level of the fire-grate is only 2 feet 7½ inches. The plate seams are single-riveted.

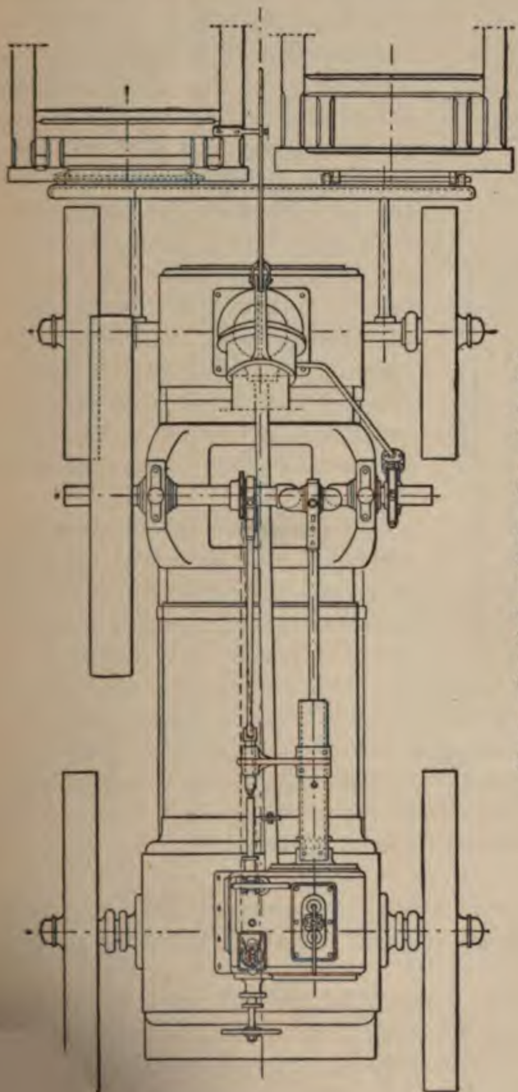


Fig. 753.—Portable Steam Engine: Plan. Scale 1/32d.

The firebox-shell is 3 feet 3 inches wide by 2 feet 6½ inches long, outside measure, leaving 2½ inches of water spaces between the fire-box and the shell, which widen upwards to 3 inches at each side. The sides and the fire-box as well as those of the shell are of one plate, tur[illegible]

the case of the fire-box to a radius of 2⅝ inches at the corners. The upper part of the shell is a semicircle turned to the radius of half the width. The front-plate and tube-plate of the fire-box are flanged to a radius of 1¼ inches outside, and are riveted to the side and top plate. The front and back plates of the shell are similarly flanged to a radius of 2 inches outside, and riveted to the outside plate. The back-plate is also cut out and flanged to join the barrel.

The fire-box is joined to the shell at the bottom with a wrought-iron frame of **Z** section, of ½-inch metal, to which each is riveted. The fire-hole is oval in form, 12 inches wide by 9 inches, formed by a wrought-iron ring about 2 inches thick inserted between the plates of the fire-box and shell, the fire-box-plate being set out to meet the ring. They are riveted together with long rivets. The ring, it is considered, is very useful for maintaining the heat of the plates round the fire-hole, when the fire-door is opened, and obviating the tendency of the firebox-plate to crack, in consequence of the sudden contraction to which, otherwise, it is exposed.

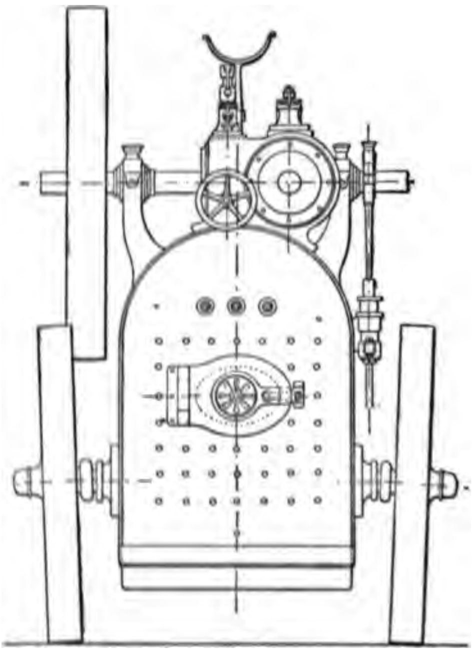
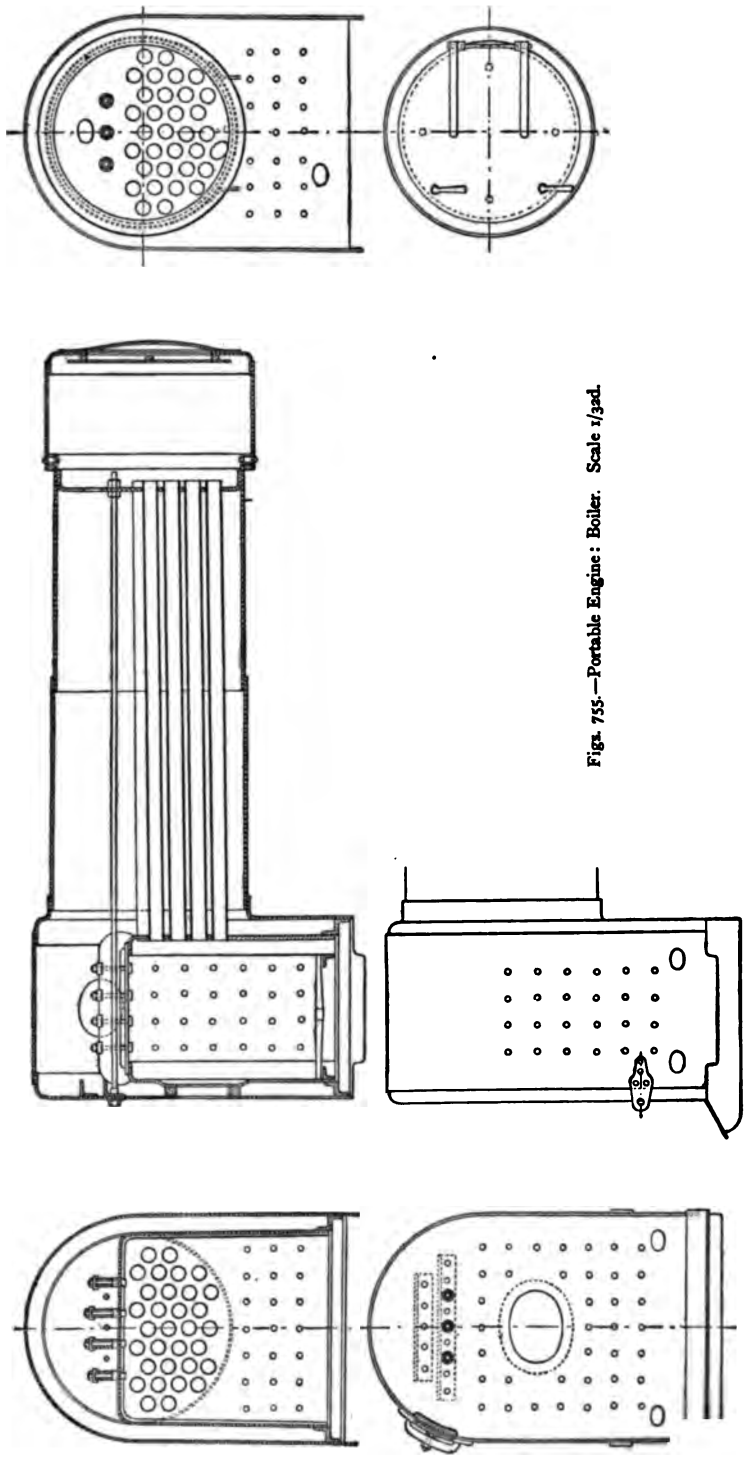


Fig. 754.—Portable Steam Engine: End Elevation. Scale 1/32d.

The walls of the fire-box are stayed to the shell with ⅞-inch stay-bolts of Lowmoor iron, spaced apart at 5-inch centres, screwed into the plates and riveted over them. The roof-plate, also, is supported by four girder-stays, placed longitudinally over the plate, 5¼ inches apart between centres, standing 1 inch clear of the plate, and taking a bearing on the back-plate and tube-plate. Each girder consists of a pair of bars of wrought iron, ½ inch thick and 3½ inches deep, riveted together ¾ inch apart. The roof-plate is bolted to each girder with four ¾-inch bolts and nuts, at 4½-inch centres.

The back-plate of the shell is stiffened at the upper part with two 3-inch angle-irons, ½ inch thick, applied transversely, one above the other, riveted to the plate.

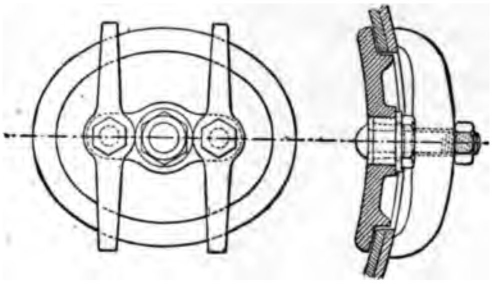
An oval manhole, 8 inches by 10 inches, figs. 755 and 756, is cut in the firebox-shell, at one side, above the fire-box. The opening is fortified with a ring of wrought-iron plate 3½ inches by ⅜ inch thick, riveted to the shell-plate about the hole. The opening is closed by … ch metal, applied from within, jointed with a ring … p



Figs. 755.—Portable Engine: Boiler. Scale 1/32d.

tightly with two ⅞-inch bolts and nuts, which pass through two wrought-iron cross-bars spanning the opening, at the outside. Oval mud-holes, 3½ inches by 2½ inches, are cut in the shell, at each corner, near the bottom of the fire-box. They are each closed by a lid and a cross-bar.

The barrel of the boiler is 6 feet 3½ inches long, measured between the firebox-shell and the smoke-box. It is constructed of two rings of plates laid telescopically, to a diameter of 2 feet 8½ inches outside next the firebox-shell, and 2 feet 7⅞ inches next the smoke-box. Each ring consists of two plates. The smoke-box tube-plate is flanged outwards to join the barrel.



Figs. 756.—Portable Engine: Manhole and Cover. Scale 1/10th.

The smoke-box is cylindrical, 2 feet 10¾ inches in diameter, 1 foot 7¾ inches long externally. It laps over the end of the barrel telescopically for a length of 2¾ inches; and is fastened to the barrel with 16 rivets, equally spaced round the circle, and a thick cast-iron strut-washer or ferule fitted between the plates to each rivet. The joint is closed by a wrought-iron ring to occupy the annular interspace behind the washers. A circular opening is formed in the front of the smoke-box, closed by a circular door of 3/16-inch plate, hinged by a pair of wrought-iron strap joints, and closed by means of two handles. A baffle-plate, ¼ inch thick, is fastened to the door, on the inside, about 1½ inches clear, as a protection from the hot currents. A mud-hole is cut in the lower part of the tube-plate, and a hand-hole in the upper part.

The longitudinal seams of the boiler are double-riveted, and the transverse seams are single-riveted, with ⅝-inch rivets, at a pitch of 2 inches.

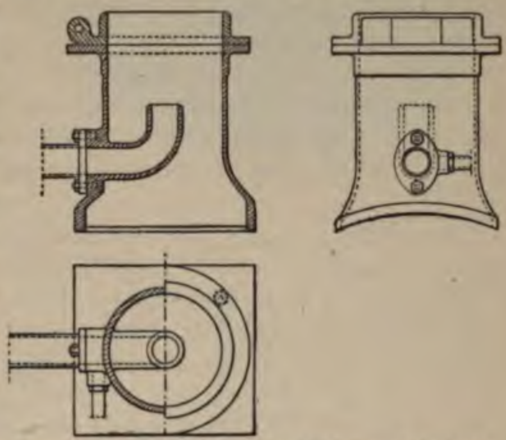
There are 32 flue-tubes of wrought iron, lap-welded, 2½ inches in diameter outside, ⅛ inch thick, 6¼ feet long between the plates, placed in vertical rows, 3½ inches apart between centres, or 1 inch clear. They are tightly fastened to the tube-plate at each end by means of an expander.

The flue-tubes act effectively as stays between the tube-plates. In addition, the extreme ends of the shell, above the level of the top of the fire-box, are stayed with three 1¼-inch through-rods, screwed into the back-plate of the firebox-shell, and secured with a lock-nut; and fastened at the other ends with two nuts inside and outside the smoke-box tube-plate.

The area of the fire-grate is 5¼ square feet. The heating surface of the fire-box is 34 square feet, and that of the flue-tubes is 136 square feet, making together 170 square feet, or 32.4 times the grate-area.

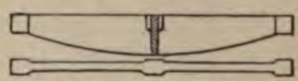
For a working pressure of 80 lbs. per square inch, the boiler is tested in steam of this pressure; and also to the extent of 160 lbs. per square inch by hydrostatic pressure.

The base of the chimney, figs. 757, is of cast iron, ⅜ inch thick, 9¾ inches in diameter inside, standing 14½ inches above the crown of the smoke-box, fastened to the smoke-box with four bolts and nuts. A cast-iron ring is hinged to the upper flange of the base, to which the chimney is fastened, and by which it may be raised or lowered. The chimney is of steel, ⅛ inch thick, 9½ inches in diameter inside, and 9 feet 2 inches in length, making a total height of about 16 feet above the level of the ground. The top of the chimney is expanded into a bell-mouth 15 inches in diameter, over which a dished shield is fixed, for baffling sparks or cinders that may be drawn through and projected by the force of the blast. The shield is placed 2 inches clear of the chimney-top.



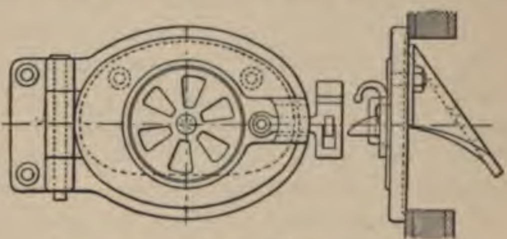
Figs. 757.—Portable Engine: Base of Chimney. Scale 1/16th.

The fire-bars are shown in figs. 758. They are of cast iron, taper in section, ⅝ inch thick at the upper edge, ⅜ inch thick at the lower edge, and 3½ inches deep. The air-spaces are ⅝ inch wide. The bars are supported on angle-iron bearers riveted to the front and the back of the fire-box. They are half an inch shorter than the fire-box, to allow for expansion by heat, or other irregularities, without causing pressure on the plates of the fire-box. The ash-pan is a shallow flat box of 3/16-inch plate, to catch ash and cinder as they fall, secured to the side plates of the fire-box, which are extended downwards for the purpose. It is well fitted so as to exclude air; whilst by means of the hinged lid or damper at the front, the draught of the fire may be regulated.



Figs. 758.—Portable Engine: Fire-bars. Scale 1/16th.

The fire-door, detailed in figs. 759, is of cast iron, ¾ inch thick. By a revolving perforated disc in front, air supplied to the fire-box through the door is regulated, and the air-current is deflected and distributed over the fuel by a baffle plate fastened on the inner side of the door.

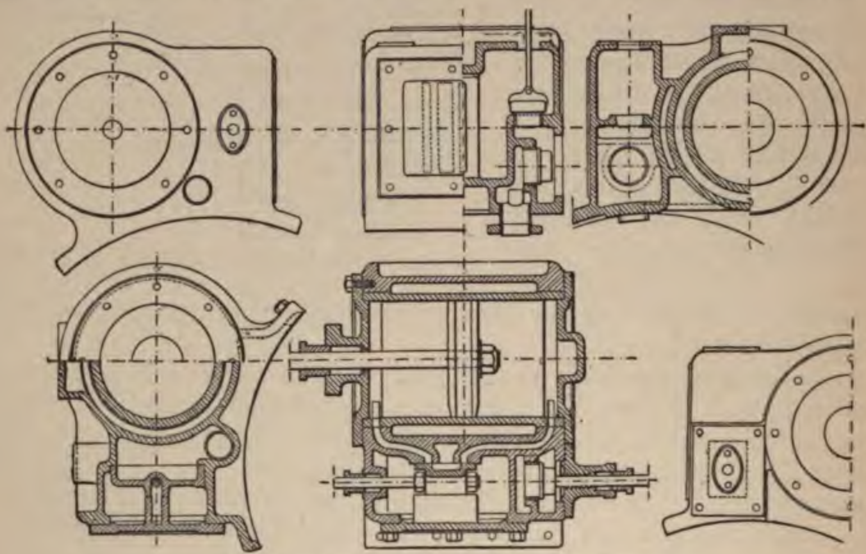


Figs. 759.—Portable Engine: Fire-door. Scale 1/10th.

The Engine.—The bed-frame of the engine is in fact the boiler, which takes the stress of the engine—the cylinder being fastened on the firebox-

shell, and the main bearings on the barrel, placed as closely as is convenient to the smoke-box tube-plate, for the sake of stiffness.

The cylinder is, as before stated, 10 inches in diameter, constructed for a stroke of 13 inches. The length between the covers is 16⅛ inches, leaving, after deducting the thickness of the piston, ¼ inch clearance at the front end, and ⅛ inch at the back end. The barrel of the cylinders is steam-jacketed; the jacket being cast in one with the valve-chest, whilst the barrel is a separate casting, $^{11}/_{16}$ inch thick, turned to fit and forced into the jacket. The jacket is of $^{9}/_{16}$-inch metal, and the steam-space is

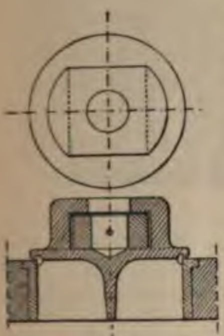


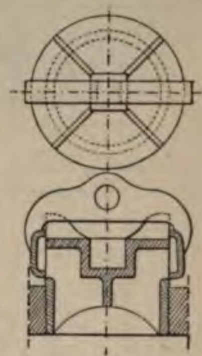
Figs. 760.—Portable Engine: Cylinder. Scale 1/16th.

⅞ inch, and is so formed that the condensation water drains directly into the boiler. The cylinder is fastened to the boiler with eight ⅞-inch bolts and nuts. The cylinder covers are ⅝ inch thick, with $^{13}/_{16}$-inch flanges, each fastened to the cylinder with eight $^{9}/_{16}$-inch screws. The valve-chest is divided into two parts, in one of which the slide-valve works. The slide-valve is of the ordinary construction, and has ⅝ inch of lap, with $^{1}/_{16}$ inch lead, and 2½ inches of travel. It is traversed by the spindle, which is of steel, ⅞ inch in diameter, and is connected to the valve by means of double-nuts at each end of the groove in which the spindle is lodged, secured in place by through-pins. The valve is not pinched by the nuts, but is free to adapt itself to the valve face. The valve slides on a flat seat at the lower side of the chest, and is held to the face of the cylinder by two ribs projecting from the valve-chest cover, which are in contact with two corresponding ribs on the back of the valve.

The other division of the valve-chest is arranged for the reception of the stop-valve and throttle-valve. The stop-valve is a 3-inch circular valve, of brass, which can be secured to its seat by means of a double-thread

screw, $1\frac{1}{8}$ inches in diameter, $\frac{3}{4}$ inch in pitch, turned by a hand-wheel, seen in figs. 752 to 754. The valve takes a flat circular bearing on its seat, only $^{1}/_{16}$ inch in width. It is of course opened under the pressure of the steam in the boiler, when released by the setting screw. Half a turn of the wheel is sufficient to fully open or close the valve. The steam is admitted to it through a short $2\frac{1}{4}$-inch pipe, one end of which is screwed into the chest, and the other end is passed through the boiler plate and screwed to it by a brass nut inside. The throttle-valve, figs. 762, is an equilibrium-valve of double entrance, $2^{9}/_{16}$ inches in diameter, of which the seat is screwed into the top of the stop-valve chamber. The valve slides vertically on the upper part of the seat, and opens one entrance a little in advance of the other. It is controlled by the governor, in connection with which it is shifted vertically by means of a $\frac{1}{2}$-inch square spindle through the top of the chest. The cylinder-casting is formed with flanges of $\frac{3}{4}$-inch metal, by which it is fitted upon the upper part of the barrel, with fitting strips, and bolted to it.

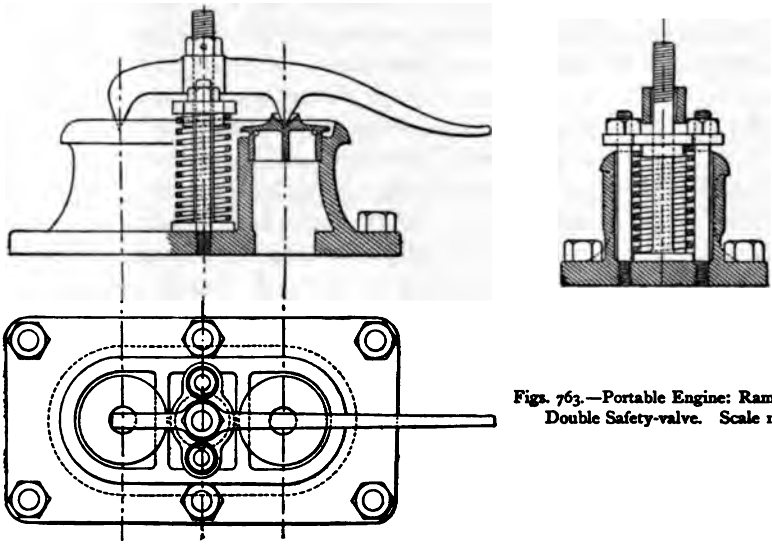

Figs. 761.—Portable Engine: Stop-valve. Scale 1/4th.


Figs. 762.—Portable Engine: Throttle-valve. Scale 1/4th.

The steam is exhausted through a $2\frac{1}{4}$-inch wrought-iron pipe, $\frac{1}{8}$ inch thick, direct to the chimney, into the base of which it is conducted by a continuation in cast iron, cast in one with the base, whence it is ejected centrally upwards into the chimney from a $2\frac{1}{4}$-inch nozzle.

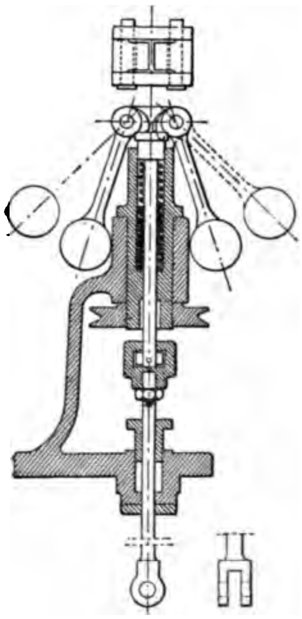
The Ramsbottom double safety-valve (figs. 763) is fixed with a level seat on the top of the cylinder. The valve-seats are 2 inches in diameter internally, and are screwed into the casting. The valves take each a flat circular bearing on the seat, $^{3}/_{32}$ inch in width. They are placed $5\frac{1}{4}$ inches apart between centres, and are held down by an intermediate helical spring of $^{3}/_{16}$-inch square steel, $1\frac{3}{4}$ inches in diameter, placed in compression. The valves are thus loaded by the direct action of the spring equally divided between them; the spring being brought to bear upon them by the medium of a cross-bar acting as a girder, formed with conical points to take a bearing on each valve. The valves are correspondingly recessed on the top to receive the conical points, so that the points of contact are nearly in the plane of the valve-seats. On this system there is no risk of the valves heeling or jamming. The pressure on the valves is regulated by the nut on the upper end of the central spindle of the spring, which takes its bearing on the cross-bar, and is secured by a through cross-pin riveted to it when finally adjusted. The spindle is held upright in a guide at the upper part, just beneath the cross-bar, through which also the spring may be placed in compression initially, before the purchase of the nut on the cross-bar is exercised on it. One end of the cross-bar is extended and

used as a lever on the spring, by which the working of the valves can be tested manually; although it is impossible to augment the load on the



Figs. 763.—Portable Engine: Ramsbottom Double Safety-valve. Scale 1/6th.

valves by weighting the lever. The safety-valves are in direct and constant communication with the boiler through the steam-jacket, by an opening into it just below the stop-valve and independent of it.

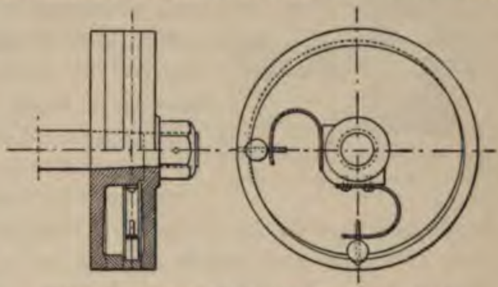


Figs. 764.—Portable Engine: Governor. Scale 1/6th.

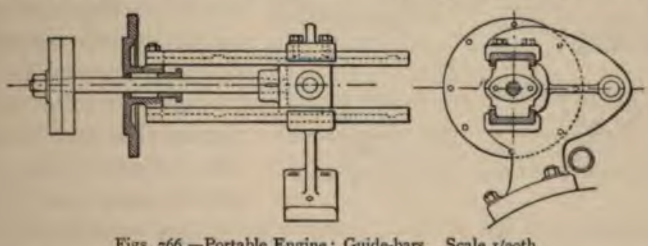
The governor, shown in detail, figs. 764, stands on and is bolted to the top of the valve-chest. Two balls are suspended from the top of a revolving spindle, and they act by means of short cams on a central rod, which is pressed downwards in proportion as the balls are spread according to the speed. The leverage of the balls thus obtained is at least as 4⅛ inches, the length of the ball-arm, to ¾ inch, the length of the cam, or as 5½ to 1. But the effective leverage is much increased in virtue of the obliquity of the action of the cams on the horizontal surface of the central rod-head. In the extreme position of the balls the leverage is effectively about as 8 to 1. The central rod is maintained in contact with the cams by a helical spring, ¾ inch in diameter, of ⅛-inch square steel, within the spindle; and is therefore pushed upwards by the spring as the balls descend and the cams rise. The spindle is driven by a square leather thong from the main shaft, in grooved pulleys about 8½ inches in diameter on the main shaft, and 3½ inches on the governor spindle, through which

the governor makes 311 turns per minute. The band is guided by two small pulleys running on a stud-pin fixed to the chimney-rest. The central rod is connected with the spindle of the throttle-valve by a swivel. The valve-spindle passes through a stuffing-box in the base of the governor; but below the stuffing-box the spindle is squared in order to prevent the communication of rotatory movement to the valve. For the position of the governor shown in figs. 764, the valve is wide open. As the governor revolves, the opening of the valve is reduced by the rising of the balls, and, if the governor be driven too fast, raising the balls to the position in dot-lining, it is closed entirely. The total lift of the valve is $5/_{16}$ inch. The governor, it is stated, regulates the speed within 5 per cent limit of variation.

The piston, figs. 765, is of cast iron, 2¾ inches thick. The body and the follower plate are of ⅝-inch metal, slightly tapered in thickness towards the circumference. They form a space 1½ inches wide for two packing-rings, each ¾ inch wide. The rings are each in one piece, cut at one place; ½ inch thick at the cut, and gradually thickened to ⅝ inch opposite the cut. They are turned to a diameter ¼ inch larger than that of the cylinder; then cut at one place, ¼ inch wide; closed up, and turned down to the size of the cylinder. When finished they remain with a tendency to spring outwards, and so fit themselves tightly to the cylinder, assisted by U-shape steel springs, ⅝ inch by $3/_{32}$ inch in section, one end of each of which is fastened to the centre of the piston, and the other end presses outwards on a cylindrical brass glut which lodges between the bevelled ends of the ring and tends to press them apart. The centre of the piston is bored with a taper to receive the piston-rod, which is of steel,



Figs. 765.—Portable Engine: Piston. Scale 1/8th.



Figs. 766.—Portable Engine: Guide-bars. Scale 1/20th.

1⅝ inches in diameter, and is tapered to 1⅜ inches for a length of 2¼ inches—making a taper of 1 in 9. The rod is fastened by a nut on the end $1^9/_{16}$ inches thick, secured by a through-pin, which serves also to hold the follower in place.

The guide-bars, figs. 766, are two in number, one above and one below the piston-rod and crosshead, and are 6 inches apart between their work

surfaces. They are of cast iron, channel-shaped in section, or of trough-section, 4¾ inches wide over the flanges, and 3¾ inches wide at the wearing surface. They are each fastened to the cylinder-cover by two ⅝-inch screws, and by two other screws to a bracket which is fastened to the boiler, at a distance of 10 inches from the outer ends of the guide-bars measured to the centre of the bracket. The angular movement of the connecting-rod causes considerable upward or downward pressure upon the guide-bars, midway in the stroke, and it is at this point that the support or bracket is fixed, instead of at the end, as is usual. The bracket serves also as a guide for the slide-valve spindle.

The crosshead, fig. 767, is a square hollow block of cast iron, of ¾-inch metal, 6 inches deep, and 3¾ inches wide, to work between the guide-bars, and 5¼ inches long. It is cottered to the piston-rod, which enters it for a depth of 3 inches, with a cotter ¼ inch thick, 1¼ inches wide. The rod is tapered to a diameter of 1⅜ inches at the end, making a taper of ¼ inch in 3 inches, or 1 in 12. The gudgeon is of steel, giving a journal 1⅝ inches in diameter, 2⅛ inches long. The sides of the crosshead are each thickened to 1¼ inches to give taper bearings to the gudgeon. The taper is ⅛ inch in the thickness, or 1 in 10. The gudgeon is secured by a collar-nut, 11/16 inch thick, at the smaller end. The gudgeon is hollow, for the reception of oil, to lubricate by a wick. The end is closed by a brass screw-plug, drilled at the upper side for the admission of the oil.

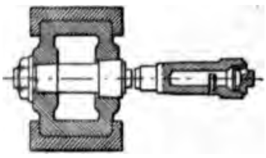
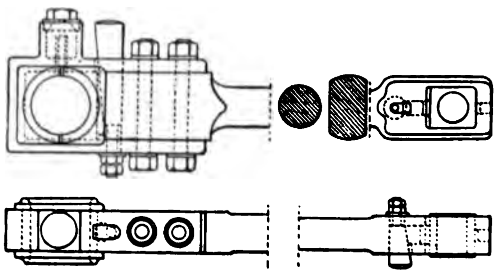


Fig. 767.—Portable Engine: Section of Crosshead. Scale 1/10th.

The connecting-rod, figs. 768, is of iron, 3 feet 8½ inches long between the centres, or 6.85 times the length of the crank. It is 1⅝ inches in diameter at the smaller end, enlarging gradually towards the larger end, where it is 2⅛ inches in diameter. The bearing at the smaller end is 1⅝ inches in diameter, 2⅛ inches long, and that at the larger end is 3¼ inches in diameter, 3½ inches long. The smaller end is solid forged, with a rectangular opening for the reception of the brasses. These are tightened by a small transverse wedge, tapering at the rate of 1 in 7, drawn up and secured by two nuts. The larger end is formed with a rectangular butt, and a strap to hold the brasses. The strap is fastened on the butt with two ¾-inch bolts and nuts, and the brasses are by a cotter, tapered at the rate of 1 in 9, which is screwed end and secured by double-nuts. An oil-cup, for syph forged solid on the strap, and stopped with a screw-pl



Figs. 768.—Portable Engine: Connecting-rod. Scale 1/10th.

The main shaft, figs. 769, 770, is of Bessemer ste

of 6½ inches. It is 3¼ inches in diameter, and has two journals, of which the journal next the crank is 5 inches long, and that next the fly-wheel is 6 inches long. The saddle-bracket, of cast iron, is hollow, of ½-inch

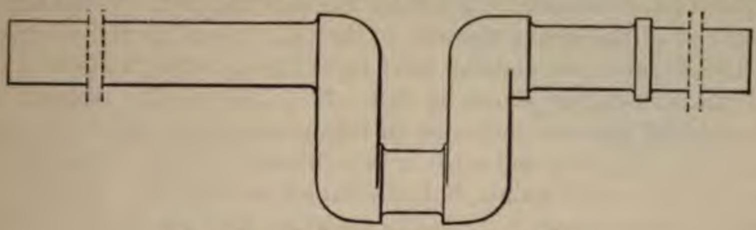
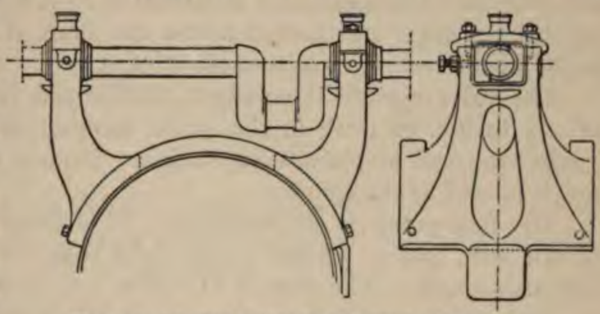


Fig. 769.—Portable Engine: Crank-shaft. Scale 1/10th.

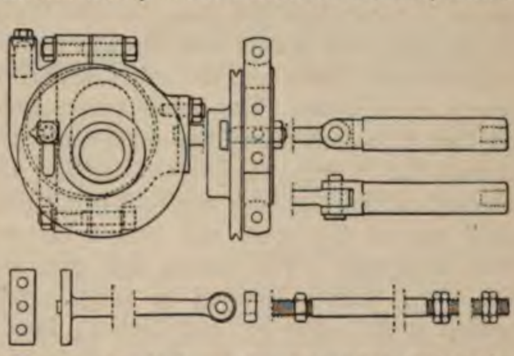
metal. It is fitted on the barrel of the boiler, to which it is fastened by four ¾-inch bolts and nuts. In plan it measures 30½ inches wide, embracing nearly half the circumference of the boiler. It is 24 inches in length. The centres of the bearings stand 22½ inches high above the edges of the saddle, and they are 35 inches apart transversely between centres. The brasses are lodged in rectangular recesses in the bracket, with caps and oil-cups. They are parted at points forming angles of 45° with the horizontal centre-line, and are tightened at each bearing by the direct application of a set-screw and jam-nut.



Figs. 770.—Portable Engine: Saddle-bracket. Scale 1/24th.

The fly-wheel is 5 feet in diameter and 7 inches wide at the rim, which is turned slightly convex to receive the driving-belt. There are six arms, oval in section.

The slide-valve is worked by a single eccentric, of cast iron, with a cast-iron strap, 6¾ inches in diameter, 1½ inches wide, on the main shaft, figs. 771. The strap is held together by two ⅝-inch bolts, which are screwed into the outer half of the strap, and are ... a jam-nut. The ...alve may be varied, so as to vary the cut-off or period of ad- ...varying of the travel the eccentric is adjustable transversely ...r this object an oblong opening is cut in the eccen



Figs. 771.—Portable Engine: Eccentric and Rod. Scale 1/10th.

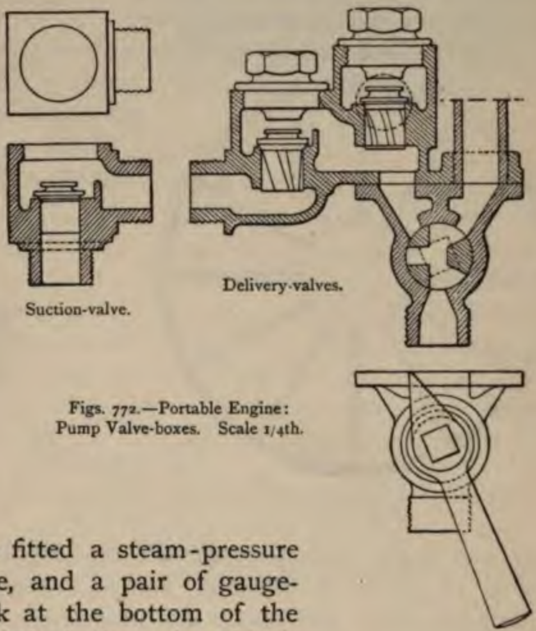
to admit of its being shifted across the shaft. To fix the eccentric in any position, it is clamped to a 9-inch disc, which is keyed on the shaft, and to which it is joggled by a bolt which is screwed into the eccentric, and is adjustable to any position in a slot cut through the disc. When the piston is at the end of the stroke, the slot in the disc, as well as the oblong opening in the eccentric are vertical, or at right angles to the horizontal centre-line of the motion, as shown in figs. 771. The angular advance of the eccentric in full throw is indicated in this figure, giving the linear advance, ($\frac{5}{8}$ inch lap + $1/16$ inch lead =) $11/16$ inch, already stated. The eccentricity of the eccentric, or its radius, in this position, equivalent to the full-gear of ordinary expansion-gear, is $1\frac{1}{4}$ inches, making the throw and the travel of the valve ($1\frac{1}{4} \times 2 =$) $2\frac{1}{2}$ inches. When the eccentric is shifted across the shaft the radius of motion is reduced, though the linear advance remains unaltered, until, when the centre of the eccentric arrives on the horizontal centre-line, the radius is just equal to the linear advance, $11/16$ inch, and the travel of the valve becomes a minimum of ($11/16 \times 2 =$) $1\frac{3}{8}$ inches. Traversing the eccentric still further across the shaft, it may be set correspondingly for the reverse motion of the engine.

The valve-spindle is enlarged, outside the valve-chest, to a diameter of $1\frac{5}{8}$ inches, to work in the guide, forming part of the bracket of the guide-bars, with ample wearing surface. Beyond the bracket the eccentric-rod is pinned to the spindle.

The feed-pump is single-acting. It is fixed vertically to the saddle at one side, and is worked direct by a cast-iron eccentric and strap on the main shaft. The ram is of brass, $2\frac{1}{8}$ inches in diameter, hollow, $5/32$ inch thick, and it has a stroke of $2\frac{3}{4}$ inches. The eccentric-rod is pinned to a stud solidly fitted into its place in the bottom of the ram, and fastened with a nut. The body of the pump is of cast iron, $\frac{1}{2}$ inch thick. It is bored out at the lower part for a depth of $2\frac{1}{4}$ inches, to fit the ram, and together with the stuffing-box gland to guide it. The water is taken into the pump at the lower end through the suction-valve at one side, and is delivered through two consecutive delivery-valves at the opposite side direct into the boiler behind the pump. The valves and valve-boxes are of brass. The boxes are screwed into the body of the pump, and as they face each other they form a direct thoroughfare for the feed-water across the pump. From the second delivery-valve the water passes through a short $\frac{3}{4}$-inch wrought-iron tube, screwed into the pump at one end, and at the other end into a cast-iron flange bolted to the boiler, with lock-nuts. The valves, figs. 772, are $\frac{7}{8}$ inch in diameter, and the lift of $3/16$ inch is defined by plugs screwed in from above. They are seated at the angle 45°, and have $3/32$ inch width of bearing. A three-way cock is connected to the delivery-valve box, communicating with the delivery-box, the overflow, and a branch from the exhaust-pipe. When this cock is shut, all the water raised by the pump is forced into the boiler. When opened, a portion of the water is discharged through the overflow pipe and returned to the supply tank [illegible] water is supplied

to the pump and returned to the cistern through india-rubber hose-pipes communicating with the tank.

To heat the feed-water, a portion of the exhaust steam is conducted through a ¾-inch iron tube to the three-way cock. The steam can be allowed, by adjusting the cock, to pass down the overflow-pipe to the feed-water. The pump is continually in action, lifting water, which is circulated through the valve-boxes when not required for feeding the boiler, and returned to the cistern. By this means the pump is kept cool at all times, and the chance of its becoming heated when not in use, and refusing to draw when turned on to the boiler, is obviated.



Figs. 772.—Portable Engine: Pump Valve-boxes. Scale 1/4th.

Mounting, &c.—On the front of the boiler are fitted a steam-pressure gauge, a glass water-gauge, and a pair of gauge-cocks, and a blow-off cock at the bottom of the fire-box for the regulation of the boiler. A 1½-inch fusible plug, of brass cored with lead, is lodged in the crown of the fire-box, and a brass screw-plug in the man-lid, by removing which a way is made for filling the boiler with water. A brass screw-plug is let into the smoke-box tube-plate, by removing which an opening is made for cleaning out the barrel of the boiler. A lubricator or tallow-cup is fixed on the valve-chest; and a pair of water-cocks are screwed into the lower side of the cylinder, coupled by a rod, and opened together, to let off condensed steam.

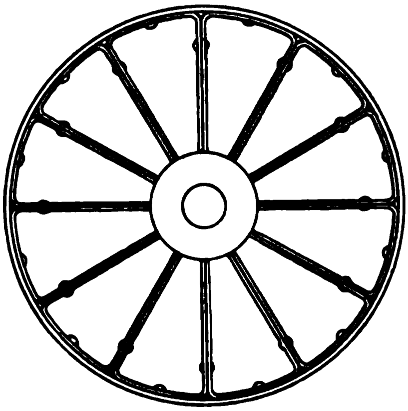
The barrel of the boiler and the steam-cylinder are clothed with slats and cased in sheets of charcoal-iron. The whole of the engine, excepting the bright parts, is painted in bright colours, picked out with lines and varnished.

The outfit includes a complete set of firing tools, spanners, a slipper and chain for scotching the wheels, and everything else that is requisite for placing the engine in complete working order, together with a waterproof cover.

With respect to the under-carriage, the boiler is, in fact, the foundation for that, as it is for the engine proper. The hind-wheels and the fore-wheels are respectively connected to the fire-box and the smoke-box, at a distance of 8 feet 4⅝ inches apart between centres. They are of wrought iron, with a cast-iron nave; and are respectively 4½ feet and 3½ feet in diameter,

and 6 inches wide at the tyres. They have each twelve arms, formed of bars of iron 3 inches by ⅜ inch in section, bent to form sectors, which are put together to form the wheel, and are bound together by the nave which is cast around them, as shown in section in fig. 774. The two halves of each arm are riveted together, and the tyre, which is ⅞ inch thick, is shrunk on the wheel and riveted to each sector.

Each hind-wheel is mounted on a short axle-arm, fig. 774, bolted to the side of the fire-box, consisting of a wrought-iron axle, on the inner end of which a round disc is cast. The bearing part of the axle is 9⅝ inches long, and is 2¾ inches in diameter, tapering to 2 inches at the end. The disc is 12 inches in diameter, and is fastened to the fire-box with six ¾-inch stud-bolts and nuts. The axle-arm is slightly inclined downwards, at the rate of 1 in 24, and the wheel is kept on the axle by a linch-pin passed through a collar. A brass cap is screwed on the end of the nave, forming a receptacle for the lubricant.



Figs. 773.—Portable Engine: Hind-wheels. Scale 1/24th.

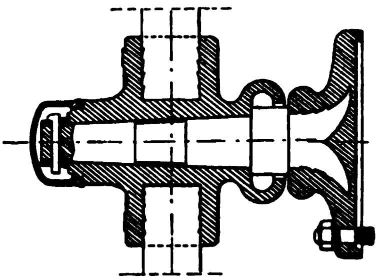
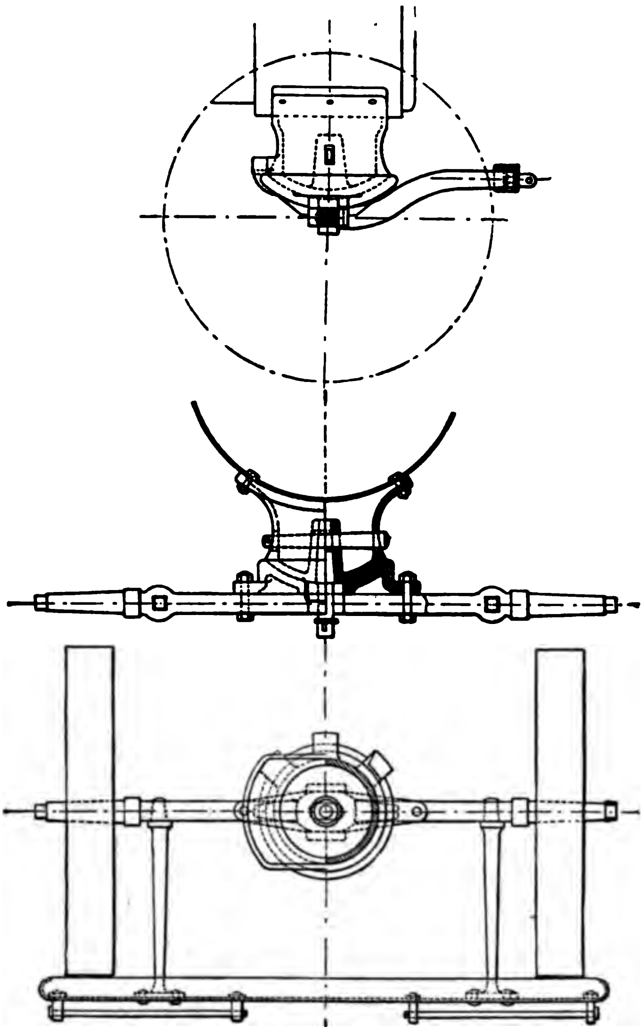


Fig. 774.—Portable Engine: Section of Nave of Hind-wheel. Scale 1/10th.

The fore-carriage, figs. 775, is constructed for turning or locking movements, and also for rocking movements by means of a ball-and-socket bearing. This bearing is of cast iron, and is 15 inches in diameter, with a versed sine or hollow of 3 inches deep. The bearing parts are of 1-inch metal, and the remainder of ¾-inch metal. The upper member is fitted to and bolted to the smoke-box with four ¾-inch bolts and nuts. The lower member is bolted to the fore-axle with two 1-inch bolts and nuts. A safety-pin or stud cottered into the centre of the upper member, passes downwards through circular openings in the lower member and the fore-axle, sufficiently wide to allow for rocking movements, and carries a large check-washer supported by a cotter through the lower end of the pin. Stops are fixed at the back of the ball-and-socket joint, by which the fore-carriage is prevented from turning round too far. The fore-axle is of wrought iron, 2½ inches square, formed with conical journals at the ends. The splinter-bar is formed of 3-inch angle-iron, ½ inch thick, and is connected to the axle by two wrought-iron arms. The horse-shafts are connected to the splinter-bar in the usual manner.

Evans & Wansbrough's contrivance f[illegible] ring the chimney

is illustrated in fig. 752, page 394; in which one of the horse-shafts is employed for counterweighting the chimney, being coupled by a rod to a bracket cast on the base-ring of the chimney. By slight exertion, one



Figs. 775.—Portable Engine: Fore-carriage. Scale 1/24th.

man can at once raise or lower the chimney. Where the chimney is heavy, the lift is effected in two stages.

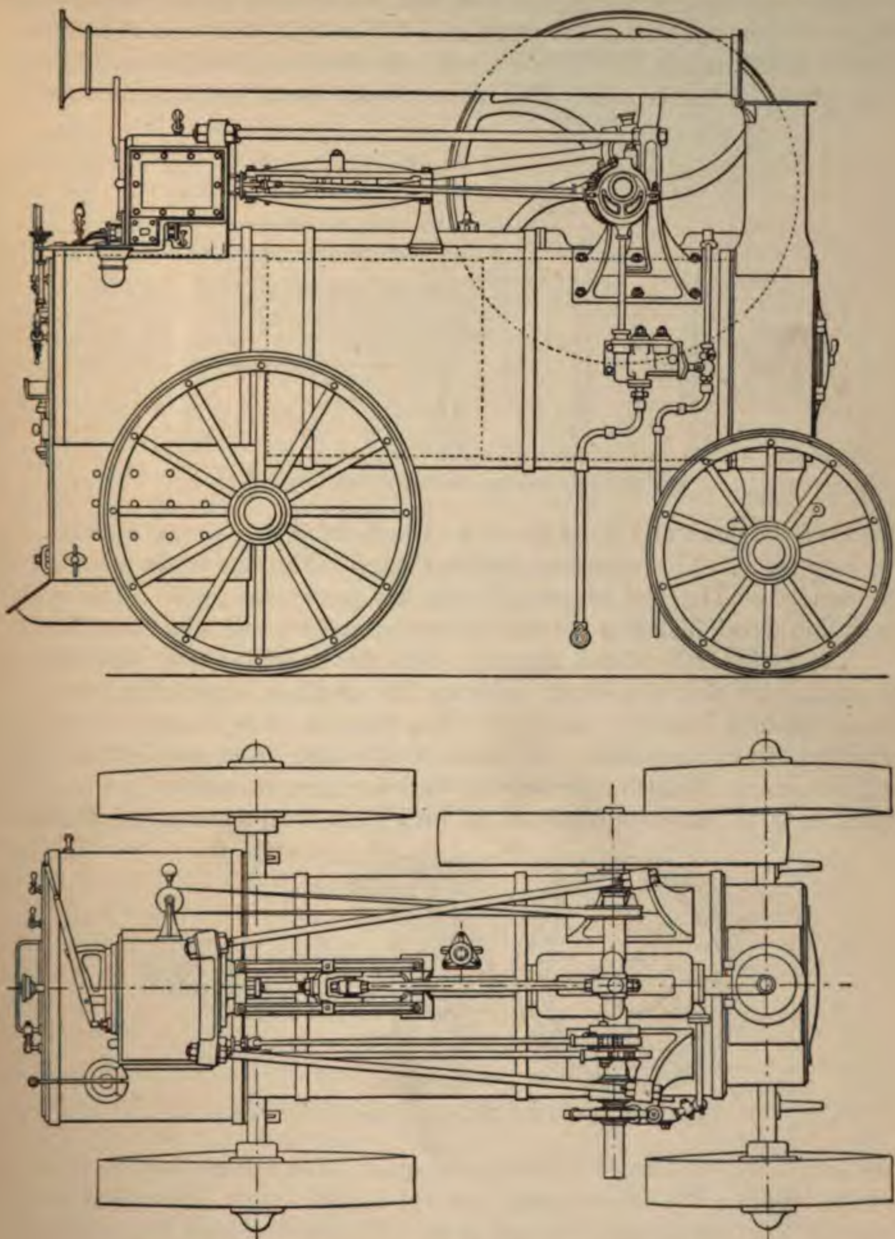
The portable engine complete weighs 5¼ tons, comprising 35 cwts. the weight of the boiler, 4½ cwts. the weight of the saddle, and 7½ cwts. the weight of the fly-wheel. The price of the engine complete is £190, or £36, 4*s*. per ton of weight, or £23, 15*s*. per nominal horse-power.

The 8-horse-power portable engine is reckoned to work to 2½ times the nominal power, or 20 indicator horse-power, with a consumption of

and 6 inches wi[illegible]
of iron 3 inch[illegible]
together to fo[illegible]
cast around [illegible]
arm are rive[illegible]
the wheel an[illegible]

Each h[illegible]

boiler, including the smoke-box, is 10 feet 10 inches. There are thirty flue-tubes 2¾ inches in diameter, 7 feet long between the plates, and 3¾ inches

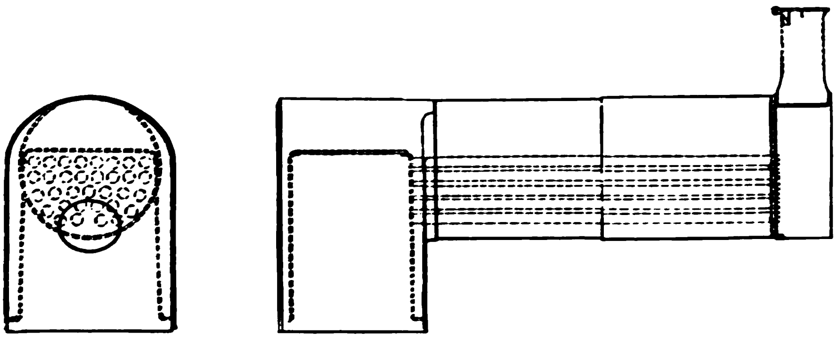


Figs. 777.—Ransome's Portable Steam Engine: Elevation and Plan. Scale 1/32d.

apart between centres. The chimney is 10 inches in diameter. The crown of the firebox-shell finishes flush with the barrel, and is elliptical in cross

section. It is stayed by the cylinder casting, which is formed with a wide base, and is bolted to the boiler.

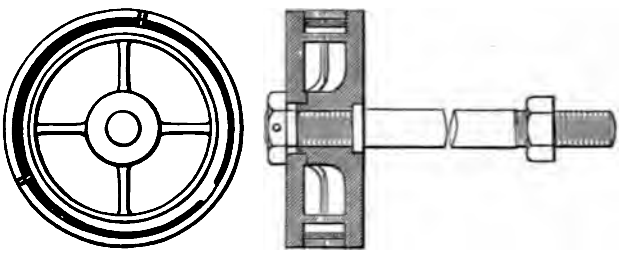
The grate-area is 6.47 square feet, and there is 164 square feet of heating surface, or 25.3 times the grate-area. The shell-plates are of Siemens-Martin mild steel, or Staffordshire iron; the fire-box is of Siemens-Martin mild steel, or Leeds iron. The plates of the barrel are 5/16 inch thick;



Figs. 778.—Ransome's Portable Engine: Boiler. Scale 1/48th.

those of the outer and inner fire-box 3/8 inch thick, and the tube-plates are 1/2 inch thick. The seams are double-riveted. The flue-tubes are of iron, lap-welded. The test pressure is 160 lbs. per square inch. The boiler is clad in wood, inclosing a 1-inch air-space, and covered with sheet iron.

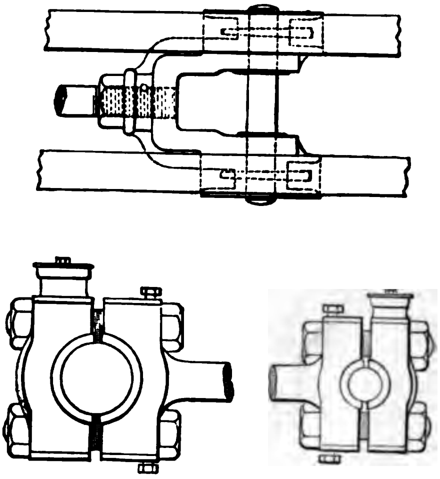
The cylinder is placed centrally over the boiler—not at one side as is usual. By this disposition midway, the crank is necessarily placed at some distance from the bearings. But there is, it is stated, no sign of weakness in consequence. No extra cranks have been supplied for such engines, many of which have been at work for more than thirty years. The cylinder is 10 inches in diameter, 3/4 inch thick, with a steam-jacket round



Figs. 779.—Ransome's Portable Engine: Piston and Rod. Scale 1/8th.

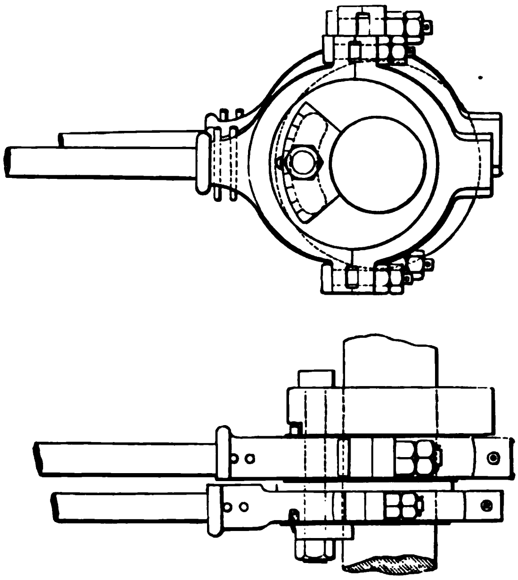
the body only, inclosing a 1-inch steam-space. The steam-ports are 3/4 inch by 5 1/4 inches; the exhaust-ports are 1 1/4 inches long. The steam is exhausted from the cylinder through a 2 3/4-inch cast-iron pipe 5/16 inch thick, on the top of the boiler, ending in a 2-inch nozzle in the chimney. The piston, figs. 779, is of cast iron, 3 1/4 inches thick, in two parts, of 3/4-inch metal, fastened together by being screwed on to the piston-rod and secured with a nut. The piston-rod is of steel, 1 9/16 inches in diameter; but in the

piston the rod is 1⅝ inches. The packing consists of two cast-iron rings, each ⅞ inch wide on the face, ⅜ inch thick. The piston-rod is screwed into the crosshead, and is secured by a check-nut, and by a pin through the base of the crosshead. By this combination the length of the piston-rod may be adjusted for the wear of the connecting-rod. The crosshead, figs. 780, is guided by two pairs of cast-iron guide-bars, each 2 inches wide, between which are the guide-blocks, of cast iron, 6 inches long, without flanges, and pinned on the ends of the gudgeon. The connecting-rod, figs. 780, is of hammered scrap iron; it is 3 feet 9½ inches in length, or seven times the length of the crank. It is made with cap-and-bolt ends. The crank-shaft is 4 inches in diameter. It carries a fly-wheel 5 feet in diameter, 9 inches wide at the rim. The bearings are 2 feet 11½ inches apart between centres, and the crank being, of course, in line with the cylinder, is midway between the bearings.



Figs. 780.—Ransome's Portable Engine: Crosshead and Connecting-rod.

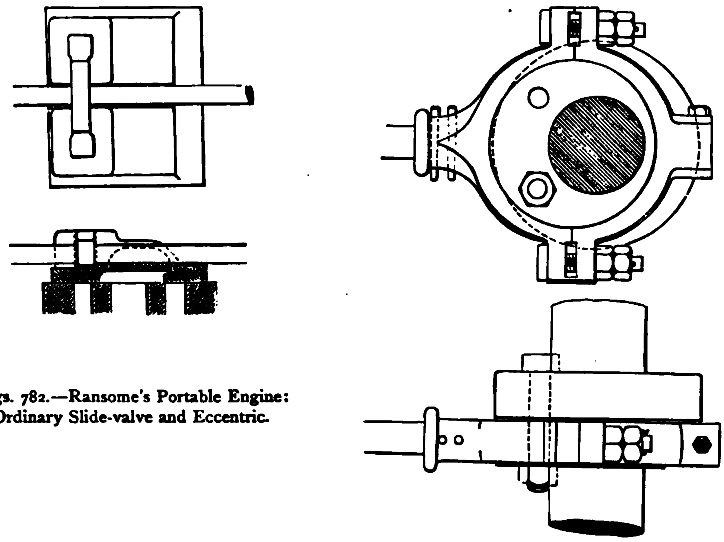
The valves and valve-gear consist of a main three-ported valve, 2¼ inches thick, which is driven by a fixed eccentric, with a fixed travel, and an expansion grid-valve, driven by a separate eccentric, by which the steam can be cut off at half-stroke, or any shorter length. The lap of the main valve is 15/16 inch, the lead 3/16 inch, and the travel 2 inches. The travel of the expansion-valve also is 2 inches. The means of adjusting the expansion-eccentric, and fixing the eccentrics, are shown in figs. 781 and 782. The expansion-eccentric is adjustable into position, on a bolt which passes through a segmental slot in the eccentric. This bolt also passes through the main eccentric, which is keyed on the main shaft. By screwing up the nut



Figs. 781.—Ransome's Portable Engine: Main and Expansion Eccentrics.

the eccentrics are fixed in the positions assigned to them. The main eccentric is 7½ inches in diameter and 1¾ inches wide; the expansion-eccentric is 7¼ inches by 1½ inches wide. The hoops are of brass, and are ¼ inch narrower than the eccentrics. They have oil-cups at the back of the shaft, in the horizontal centre-line—more plainly shown in figs. 781. The rods are fastened in sockets cast on the hoops, with two round pins to each.

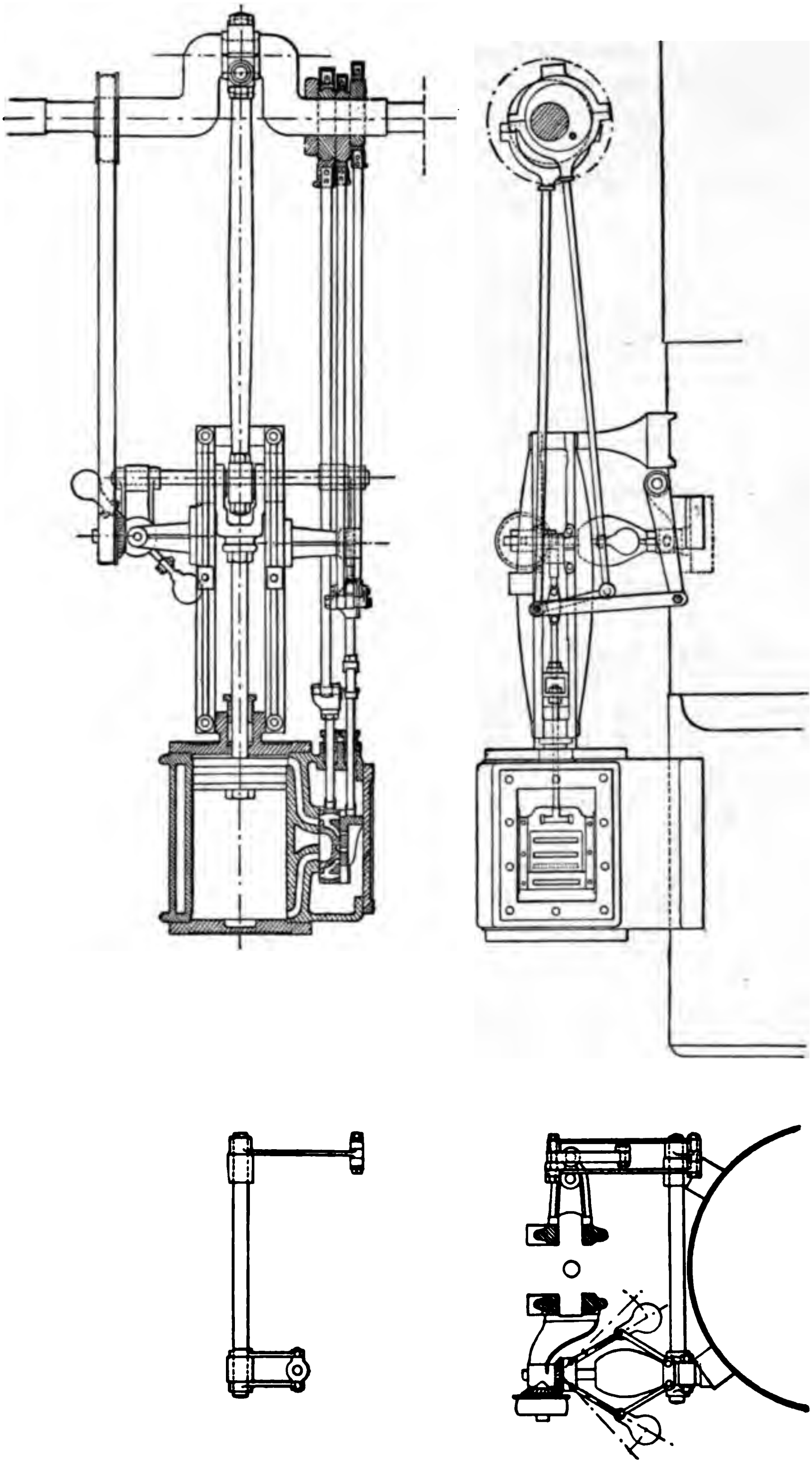
Although many of the portable steam engines manufactured by Messrs. Ransomes, Sims, & Jefferies are fitted with a superposed expansion-valve



Figs. 782.—Ransome's Portable Engine: Ordinary Slide-valve and Eccentric.

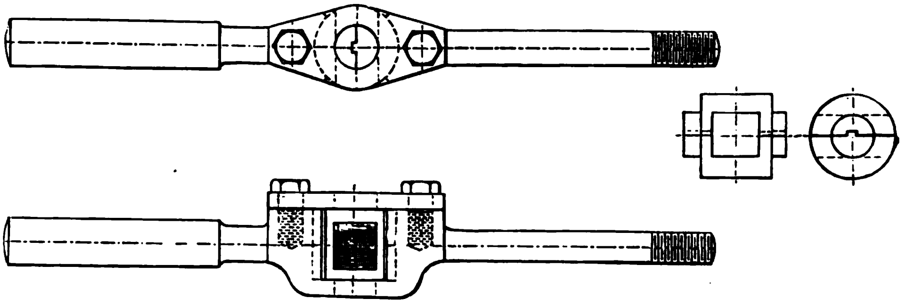
as described, the greater proportion are fitted with a plain single slide-valve and eccentric, as shown in figs. 782. The eccentric is bolted in position to a disc fixed on the main shaft, and an alternative hole is made in the eccentric, through which it may be bolted to the disc in position suitable for reverse running. The valve has ⅞ inch of lap and $^3/_{16}$ inch of lead; and cuts off at half-stroke.

An automatic variable-expansion gear, figs. 783, is often applied by Messrs. Ransomes & Co. to portable steam engines for driving machinery, in which the power required varies quickly. The main valve is of the same ruling dimensions as already given; and, as before, it is driven directly by one eccentric, with a fixed cut-off and expansion. The expansion-valve is worked by a shifting link-motion, of which the throw of each eccentric is 2¼ inches, and the maximum travel of the valve is a little less. The three eccentrics are separate, but are fastened by one bolt and nut to a disc keyed on the shaft. They have alternative holes, by which they may be fixed for reverse running. The eccentric-rods are 4 feet 1½ inches long between centres, and the link is 7½ inches long, very short in proportion to the rods. The link is a single solid bar of rectangular section, ⅞ inch by



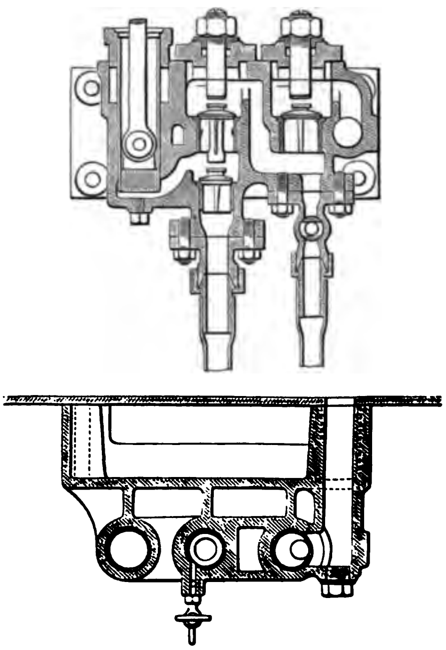
Figs. 783.—Ransome's Portable Engine: Cylinder and Variable-expansion Gear, with Link-motion. Scale 1/20th.

1 inch; and it works through a steel die put together, in two halves, into a circular socket formed in the valve-spindle, within which the die reciprocates to the changing angle of the expansion-link; as detailed in figs. 784.



Figs. 784.—Ransome's Portable Engine: Detail of Link-connection with Expansion-valve Spindle. Scale 1/4th.

The valve-rod or spindle is ¾ inch in diameter, in two pieces, united by a brass link, to which each piece is fixed: the inner piece by double-nuts, and the outer piece by being screwed into the link, and secured by a jam-nut. Thus the length of the spindle may be accurately adjusted. The outer end of the outer piece is enlarged to 1 inch in diameter, and works in a cast-iron guide 3 inches long, bolted to the guide-bars. The valve-rods are formed with crossheads received in corresponding recesses found in the main and the expansion valves. The expansion-link is sustained by a link from a wyper on a transverse shaft above the boiler, the other end of which is connected by a wyper to the counterweight of the governor. The weight of the expansion-link and rods, except what is carried by the eccentrics, is more or less balanced by a counterweight for different speeds, the unbalanced weight being sustained by the governor, through the medium of the transverse shaft and the wypers; and as these are in the ratio of 2 to 1 the dead stress is equal to twice the sustained load.



Figs. 785.—Ransome's Portable Engine: Continuous-action Feed-pump.

The governor is on Porter's system, and is driven by a band from a pulley on the main shaft, at a speed of 230 turns per minute.

The weight of the boiler is 50 cwts.; that of the engine 40 cwts.; wheels, axles, &c., 15 cwts.; total weight 5 tons.

The feed-water is supplied to the boiler by a continuous-action pump. The cock for regulating the supply is placed in the discharge-pipe instead of the suction-pipe; and when the water is to be pumped into the boiler, this cock is shut. When the supply of water is to be cut off from the boiler this cock is opened, when the discharged water returns to the tub or tank, and intermixed with it is a portion of the exhaust steam led from the exhaust-pipe by a pipe which joints the overflow-pipe. Thus the feed-water is heated by wasted steam. The sectional view, figs. 785, shows the internal arrangement of the pump, but without any connection with the exhaust-pipe. The inlet passage for the water from the pump to the boiler is shown in horizontal section. It may be easily cleaned by undoing the screw plug.

STRAW-BURNING PORTABLE STEAM BOILER.

CONSTRUCTED BY MESSRS. RANSOMES, SIMS, & JEFFERIES.

The introduction of this straw-burning boiler, shown in fig. 786, is due to the original patent of Head & Schemioth, taken in January, 1872, which comprises principally the feeding apparatus at the front of the boiler. This patent was supplemented by a second patent, by Mr. John Head, in the

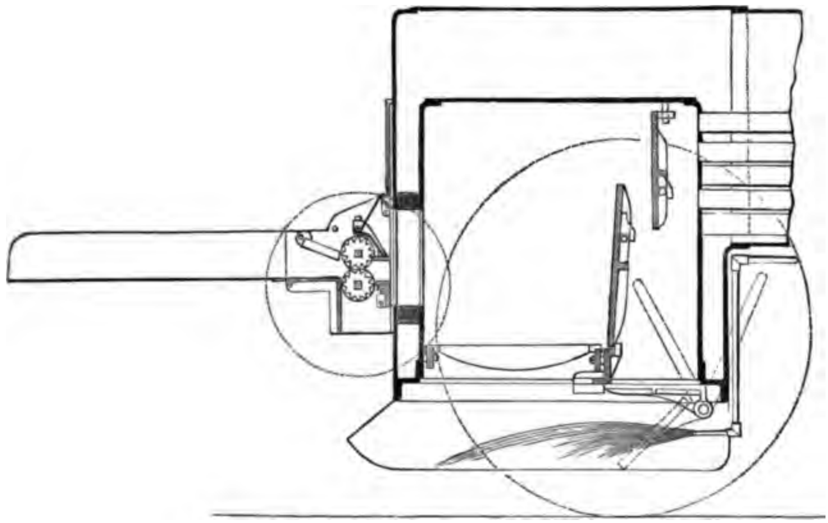


Fig. 786.—Ransome's Straw-burning Portable Steam Boiler. Scale 1/24th.

same year, which comprised amongst other things a water-pipe from the feed-pump, introduced into the ash-pan, through which the ash-pan was automatically supplied with a continuous jet of water, by which stray embers were extinguished, and so reducing the danger of working near straw-stacks. More recently, in 1877, Messrs. Head & Jefferies' baffle-plates within the fire-box, in front of the tube-plate, were added, whereby the liability to block the tubes by deposit from the burning material been entirely obviated. A long running can be made without any s

attention to the state of the tubes; in fact, it is stated that, after a day's work, the quantity of deposit on the tubes and in the smoke-box is but little more than when coal is used.

For straw-burning, the fire-box is made of 1½ times the length of the ordinary fire-box, in order, whilst maintaining the same grate-area, to make room for the bridge and baffle-plate, and to increase the fire-box heating surface. In the illustration, fig. 786, the fire-box is 3 feet long, and the grate is 2 feet long, with ordinary fire-bars. The two baffle-plates are of cast iron, ⅝ inch thick, with stiffening flanges: one suspended at the end of the grate, acting as a bridge, 21 inches high, and the other suspended directly in front of the flue-tubes. For the purpose of removing any ash that may fall between the bridge and the tube-plate, a door or flap hinged to the back of the fire-box, and closing the interspace, is let down, and the ash escapes into the ash-pan. It is kept closed while the boiler is at work, the lever being pulled back and secured by a catch on the axle.

The straw is fed through a rectangular opening into the fire-box by a pair of serrated rollers 4¼ inches in diameter, making 50 turns per minute, between which the straw is seized.

The average heating surface of the boiler is at the rate of from 20 to 25 square feet per nominal horse-power. For the 10-horse-power boiler, there is 193.5 square feet of surface. The consumption of straw is from 10 pounds to 12 pounds per break horse-power per hour. In actual practice, the straw-crop yields sufficient fuel for thrashing the corn, grinding the grain into flour, and cultivating the land for the next crop; leaving unused from 5 per cent to 15 per cent of the straw. Thus the grain crop—so far at least as wheat is concerned—supplies its own fuel for all the agricultural operations.

The following are the results of special comparative trials of portable steam engines fitted with the straw-burning apparatus, and the ordinary fire-box. The first was a 10-horse-power engine, having a 10-inch cylinder, with a stroke of 13 inches, making 140 turns per minute, yielding 20 horse-power at the break. The heating surface was over 184 square feet. The fire-box had a grate-area of 6.47 square feet. The trial lasted 2 hours 16 minutes, when the straw was consumed at the rate of 218.6 pounds per hour, or 33.8 pounds per square foot of fire-grate, or 10.93 pounds per break horse-power per hour.

The second engine was of 8 horse-power, having an ordinary fire-box, with a grate-area of 5.12 square feet, and 148 square feet of heating surface. The cylinder was 9⅜ inches in diameter, with a stroke of 12 inches, making 140 turns per minute. During a run lasting 3 hours 21 minutes, 16.75 horse-power was given out at the break; 282.4 pounds of straw was consumed per hour, or 55.2 pounds per square foot of fire-grate, or 16.86 pounds per break horse-power per hour.

Here it appears that by the employment of the straw-burning apparatus, the consumption of straw per horse-power produced was reduced one-third.

CHAPTER L.—CONCLUDING REMARKS ON ORDINARY PORTABLE STEAM ENGINES.

The descriptions already given of portable engines apply substantially, with but slight differences, to the engines of most leading English manufacturers.

It has been objected to the use of tie-rods connecting the cylinder and the main-shaft brackets, that the stress induced by the expansion of the boiler, while steam is being raised, the rods remaining cold, must be much in excess of the strains due to the ordinary work of the engine. To obviate this objection, Messrs. Ruston, Proctor, & Co. provide a means of heating the stays by making them tubular, and admitting steam from the boiler into them. By this arrangement, expansion takes place alike above and below. Messrs. Marshall, Sons, & Co. obviate the difficulty by making the brackets of wrought-iron plates, flexible, so that while the upper part of the bracket is rigidly connected to the cylinder by the stay-rods, the lower part is relatively free to move with the expansion and contraction of the boiler.

Messrs. Hornsby & Sons, according to one of their designs, place the cylinder and valve-chest entirely in the steam-space of the boiler, in an upward extension of the fire-box: so thoroughly steam-jacketing the cylinder.

Many manufacturers fit their engines, when desired, with automatic expansion-gear, as already exemplified in the practice of Messrs. Ransomes, Sims, and Jefferies: the travel of a separate expansion-valve, and therefore also the period of admission, being varied by the action of the governor in controlling the position of a link connected to the eccentric rod or rods. Nearly all makers fit their engines, when desired, with the Meyer expansion-gear.

Many firms fit their portable engines with chimney-lifters. Mr. James Coultas, Grantham, was the first who adopted such apparatus, consisting of a small winch fixed to the front of the smoke-box, to which a chain from the top of the chimney was led, the chain being held about 10 inches clear of the lower end of the chimney for the sake of a purchase to start the chimney from its horizontal position. Messrs. Marshall, Sons, & Co. employ, for the same purpose, a screw system fitted to the lower flange of the chimney.

Table No. 166 gives particulars of single-cylinder portable engines of various powers; and table No. 167 gives the same for double-cylinder engines. These quantities are averages of the best practice.

For the measure of nominal horse-power the dimensions of the cylinders given in the tables are such as to give about 11 circular inches of piston-area per horse-power.

The speed of piston is at the rate of from 250 feet to 270 feet per minute.

The area of fire-grate is at the rate of from ¾ square foot to ½ square foot per nominal horse-power.

The area of heating surface is at the rate of from 22 square feet to 16 square feet per nominal horse-power.

Table No. 166.—Single-cylinder Portable Steam Engines:—Averages.

Nominal Horse-power.	Engine.						Boiler.				Price.
	Cylinder.		Diameter of Shaft.	Fly-wheel.		Turns per Minute.	Area of Fire-grate.	Heating Surface.			
	Diameter.	Stroke		Diameter.	Breadth			Area.	Per Nominal H.P.	Ratio to Grate-area.	
H.P.	inches.	inches	inches.	ft. ins.	inches.	turns.	sq. ft.	sq. ft.	sq. ft.	ratio.	£
2½	5¼	9	2¼	3 6	4½	150	2.20	55.0	22.0	25	100
3	6¼	10	2¼	4 0	5	150	2.50	63.6	21.2	25.5	110
4	6¾	10	2½	4 0	6½	150	3.00	80.9	20.22	27	130
5	7¼	12	2⅝	4 6	6½	125	3.60	101.4	20.28	28.2	150
6	8¼	12	2¾	4 10	6½	125	4.10	120.7	20.12	29.4	160
7	8¾	12	2⅞	4 10	6½	125	4.62	140.0	20.0	30.3	175
8	9½	12	3	5 0	7½	125	5.25	168.7	21.1	32.1	190
9	10¼	12	3⅛	5 0	8½	125	5.87	178.4	19.8	30.4	205
10	10¾	14	3⅜	5 6	8½	115	6.25	194.3	19.43	31.1	225
12	11¾	14	3⅝	5 6	9	115	7.10	219.4	18.3	31.3	250

Table No. 167.—Double-cylinder Portable Steam Engines:—Averages.

Nominal Horse-power.	Engine.						Boiler.				Price.
	Cylinder.		Diameter of Shaft.	Fly-wheel.		Turns per Minute.	Area of Fire-grate.	Heating Surface.			
	Diameter.	Stroke		Diameter.	Breadth			Area.	Per Nominal H.P.	Ratio to Grate-area.	
H.P.	inches.	inches.	inches.	ft. ins.	inches.	turns.	sq. ft.	sq. ft.	sq. ft.	ratio.	£
8	6¾	12	2⅞	5 0	7½	125	5.25	168.7	21.1	32.1	215
10	7¾	12	3⅛	5 0	8½	125	6.25	194.3	19.43	31.1	250
12	8¼	12	3¼	5 0	8½	125	7.1	219.4	18.3	31.3	275
14	8¾	12	3½	5 0	9	125	7.8	245.7	17.5	31.5	310
16	9¼	14	3¾	5 6	9	115	8.6	271.7	16.9	31.6	340
18	10¼	14	4⅛	5 6	9	115	9.6	303.5	16.75	31.6	375
20	10½	16	4½	6 0	10	100	10.5	332.2	16.6	31.7	410
25	11½	16	4¾	6 0	11	100	12.8	405.8	16.03	31.8	470
30	12½	18	5	6 6	12	90	15.0	477.0	15.9	31.9	540

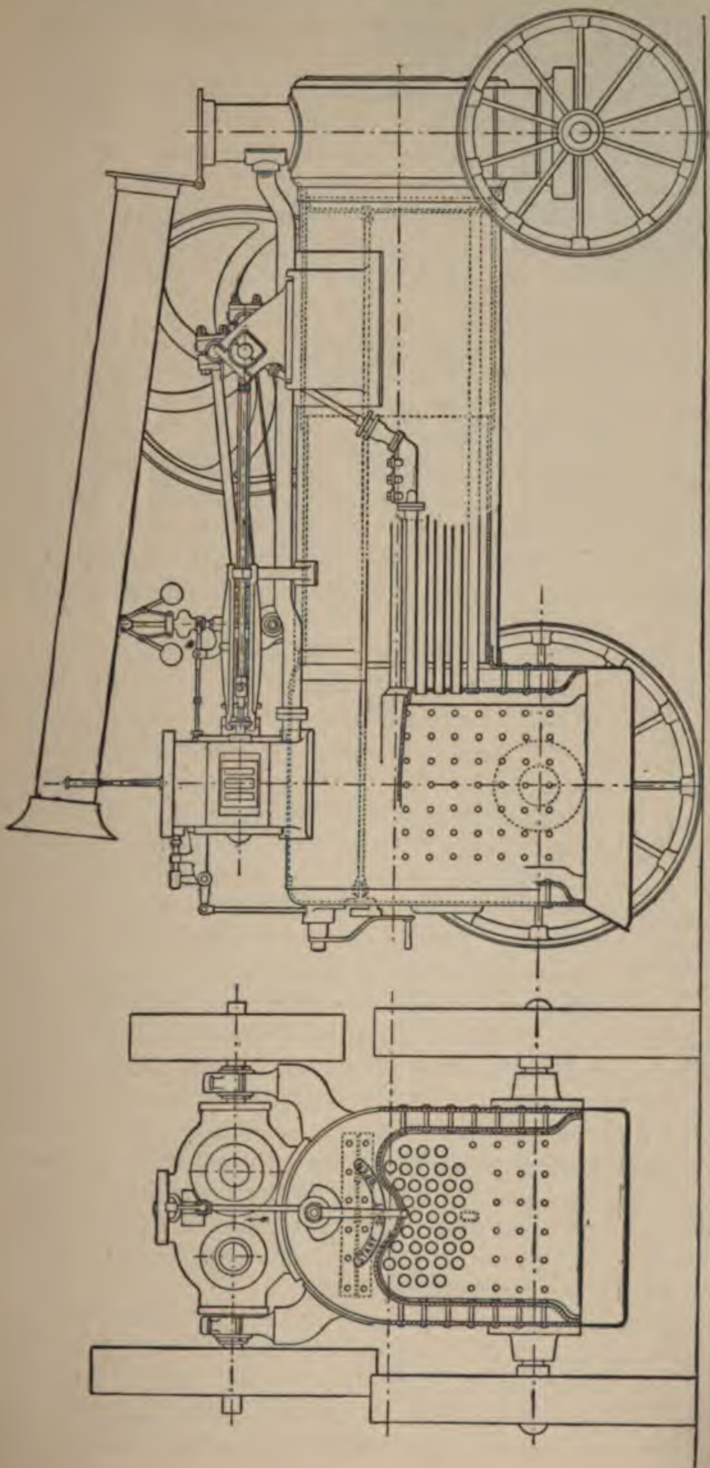
The area of heating surface varies from 25 times to 32 times the grate-area. It may be taken that, generally, water can be evaporated at the rate of 2 cubic feet per square foot of fire-grate per hour, for a consumption of 15 pounds of good coal per square foot per hour, and that the indicator power can be got up to from 2½ times to 3 times the nominal power.

Chapter LI.—"A" COMPOUND PORTABLE STEAM ENGINE.

CONSTRUCTED BY MESSRS. R. GARRETT & SONS, LEISTON, SUFFOLK.

(Cylinders 7 inches and 10½ inches in diameter, stroke 10 inches.)

It appears that Messrs. John Fowler & Co., Leeds, exhibited a compound semi-portable engine at the show of the Royal Agricultural Society,



Figs. 787.—R. Garrett & Sons: "A" Compound Portable Steam Engine. Scale 1/32d.

Kilburn, in 1879; in which the cylinders were fastened to a separate foundation-plate placed beneath the boiler. Messrs. R. Garrett & Sons, Leiston, were the first who exhibited a compound portable engine, which was shown at the Society's Meeting, Carlisle, in 1880. In this engine, the cylinders were fastened to the upper surface of the shell of the boiler.

The compound portable engine resembles in general arrangement the single-cylinder portable engines already described. The two cylinders are placed horizontally side by side on the top of the firebox-shell, and are connected to a double-crank shaft carried in bearings on a saddle on the boiler near the smoke-box.

The boiler-plates are of Landore steel, of a standard tensile strength of from 29 tons to 30 tons per square inch. The shell-plates are 5/16 inch thick. The plates of the fire-box and the tube-plate of the smoke-box are ½ inch thick. The firebox-shell is 3 feet 4 inches long, 3 feet wide, and 4 feet 2 inches high, outside. The front and back plates are flanged to join the sides and top. The barrel is in two rings, each being one plate, of which the greatest diameter outside is 2 feet 8 inches, and the minimum inside diameter 2 feet 6¾ inches.

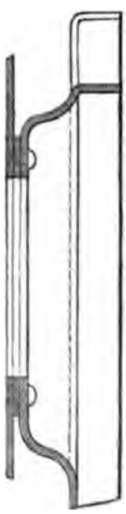


Fig. 788.—Garrett's Compound Portable Engine: Fire-doorway. Scale 1/10th.

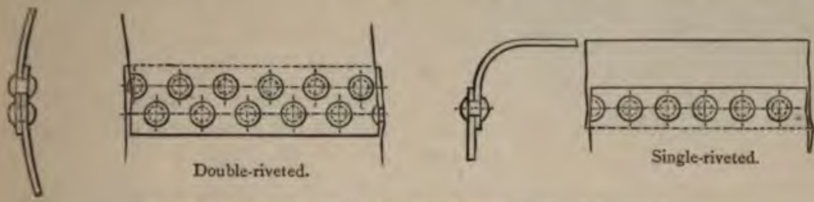
The fire-box is 2 feet 8½ inches long by 2 feet 4⅝ inches wide inside, and 2 feet 10 inches high. The highest part of the roof is 2 feet 5 inches above the fire-grate. The water-spaces are about 3 inches wide. The roof of the fire-box is corrugated to form two longitudinal arches separated by an invert; whilst it is slightly arched longitudinally, having a rise of about an inch. By this conformation, in which the corrugation is 4 inches high, the roof is sufficiently stiffened to resist the pressure of the steam without the aid of the usual roof-stays. The results of experience have shown that the resistance of this roof is perfectly satisfactory; and that the durability of the fire-box is increased materially by the freedom for expansion and contraction, whereby any considerable scaling of the crown-plate is prevented.

Messrs. Garrett observe that the evaporative efficiency of their boilers constructed with a corrugated roof to the fire-box is greatly increased by the water-pocket formed between the corrugations, and by the freedom from scale consequent upon the elasticity of the structure.

The fire-box is set out at the bottom to join the shell, to which it is riveted directly. It is dished at the fire-hole, as in fig. 788, and is joined to the shell with a thin ring between them.

The longitudinal seams of the shell are double-riveted, the transverse seams of the shell and those of the fire-box are single-riveted, as in figs. 789. The rivets are ¾ inch in diameter, and are cup-headed at each side of the joint, the rise of the cup-heads being ⅜ inch, and their diameter 1¼ inches. For si[illegible]he rivets are pitched

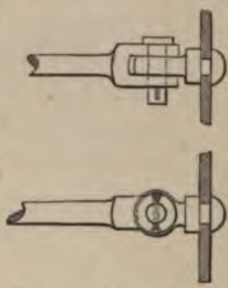
at $1^{15}/_{16}$ inches, and the plates have $2\frac{1}{8}$ inches of lap, or $1^{1}/_{16}$ inches at each side of the centre-line of the rivets. For double-riveting the lap is $3^{9}/_{16}$ inches, of which there is $1^{7}/_{16}$ inches the "spacing" or distance apart of the centre-lines of the two rows of rivets, and $1^{1}/_{16}$ inches at each side.



Figs. 789.—Garrett's Portable Engine: Riveted Joints. Scale 1/10th.

The rivets are pitched at $2\frac{3}{8}$ inches longitudinally, and $1^{13}/_{16}$ inches diagonally or 77 per cent of the longitudinal pitch.

The walls of the fire-box are connected to the shell by $\frac{3}{4}$-inch stay-bolts of mild steel, Siemens-Martin, at $4\frac{1}{2}$ inches pitch, screwed into the plates and riveted over. The upper part of the shell is stayed by three $1\frac{1}{8}$-inch rods, which are pinned to a T-iron bar 5 inches by 3 inches, riveted across the back of the firebox-shell, and to eye-studs, figs. 790, riveted to the smoke-box tube-plate.



Figs. 790.—Garrett's Portable Engine: Eye-studs at Smoke-box Tube-plate, for Longitudinal Tie-bolts. Scale 1/10th.

There are 37 iron flue-tubes, 2 inches in diameter externally, No. 11 gauge in thickness, $6\frac{3}{4}$ feet in length between the plates, pitched at 3 inches between centres and 1 inch clear. They are fixed into the fire-box tube-plate by being expanded and beaded or riveted over, as in figs. 791, and into the smoke-box tube-plate, which is bored out to a diameter of $2\frac{1}{8}$ inches, by simply expanding, as in figs. 791. They project $\frac{3}{4}$ inch from the face of the tube-plate, in order that when they are burnt away at the fire-box end they may be driven back from the smoke-box, re-expanded at each end, and beaded at the fire-box end.

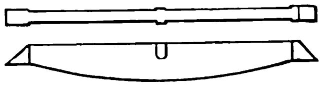
The regular water-level is 4 inches above the crown of the fire-box; and the capacity of the steam space is about $14\frac{1}{2}$ cubic feet.

The smoke-box is of $\frac{1}{4}$-inch plates, and is 22 inches long inside, and 3 feet in diameter, making the total length of the boiler-shell and smoke-box over all 11 feet 7 inches.

Figs. 791.—Garrett's Portable Engine: Fastenings, Flue-tubes. Scale 1/8th.

The chimney is 9 inches in diameter, No. 14 gauge in thickness, and is 10 feet 9 inches high above the smoke-box, or 14 feet 5 inches above the level of the fire-grate. The chimney and the base are hinged together by means of angle-iron hoops. A lever-arm is sometimes provided for raising and lowering the chimney.

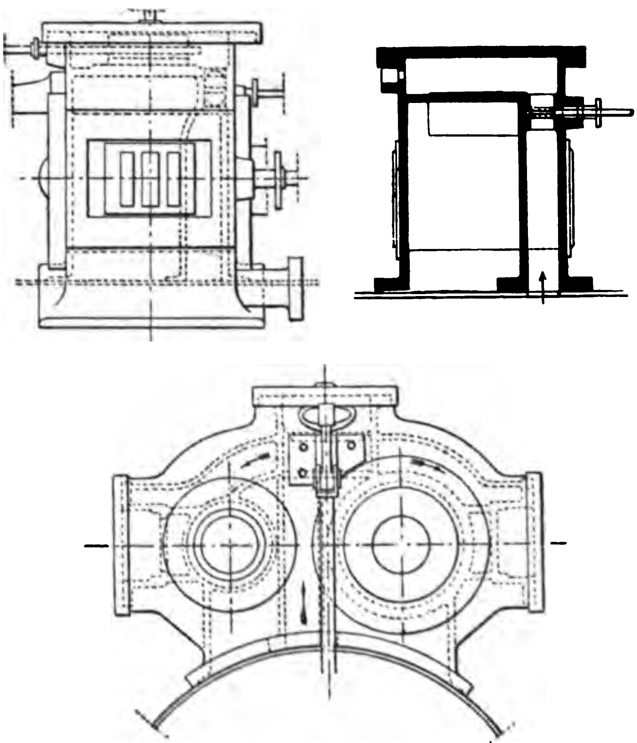
The fire-bars, figs. 792, are of cast iron, 17 in number, 2 feet 8 inches long, of which 15 bars are $^{13}/_{16}$ inches thick, with $^{5}/_{16}$-inch air-spaces; and two are $2\frac{1}{8}$ inches thick. They are bevelled downwards at each end, in order to obviate the jamming of clinker between the ends of the bars and the fire-box.



Figs. 792.—Garrett's Portable Engine: Fire-bars. Scale 1/20th.

The area of the fire-grate is 6.3 square feet; and the heating surface comprises 29 square feet of fire-box surface, and 126 square feet of tube surface—together, 155 square feet, or 24.6 times the grate-area.

The cylinders, figs. 793, are in one casting, and are 7 inches and $10\frac{1}{2}$ inches in diameter respectively, with a stroke of 10 inches. They are $^{11}/_{16}$ inch thick, and the covers are $\frac{5}{8}$ inch thick. The areas of the pistons are as 1 to 2.25. The steam-ports for each cylinder are $1\frac{1}{8}$ inches by 5 inches, making $5\frac{5}{8}$ square inches of area, or $^{1}/_{6.8}$ part of the area of the first piston, and $^{1}/_{15.4}$ part of the area of the second piston. The slide-valves are set to cut off at half-stroke in each cylinder; and the nominal ratio of expansion in each cylinder being 2, the total nominal ratio is ($2 \times 2 =$) 4. But the clearance between the piston and the valve at each end of the stroke is to be reckoned with. It is equal to 13.8 per cent of the stroke for the first cylinder, and to 8.8 per cent for the second cylinder; and the actual ratios of expansion are, therefore, respectively as (50+13.8) to (100+13.8), or 1 to 1.78; and as (50+8.8) to (100+8.8), or 1 to 1.85, and the total compounded actual ratio is as 1 to 3.30.



Figs. 793.—Garrett's Portable Engine: Cylinders. Scale 1/16th.

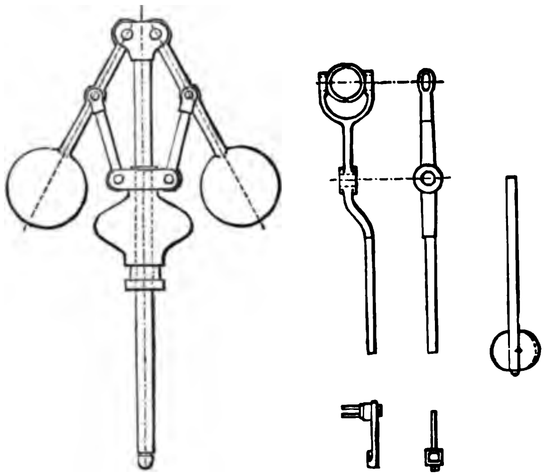
The clearance spaces and the intermediate space between the cylinders, consisting of passages and slide-chest, are here stated for comparison:—

Total clearance in the first cylinder,	53	cubic inches,	or .030	cubic foot.
Do. second do.,	76	,,	or .044	,,
Total space between the cylinders,	410	,,	or .237	,,

The receiver space between the cylinders is not quite half of the working capacity of the second cylinder which is supplied by it. The cylinder capacity is 866 cubic inches, or half a cubic foot.

The cylinders are clad with felt sheets and sheet-iron casing.

Steam is admitted direct from the boiler to the starting-slide chest at the top of the cylinder-casting, through a passage 2¾ inches in diameter, or $^1/_{6.5}$ part of the area of the first piston. The steam-joint between the cylinder and the boiler is formed by accurately chipping the casting, and the use of a thin ring of asbestos packing. The slide travels horizontally on a flat face, and steam can be admitted to both cylinders at once. It is moved by hand through two bell-crank levers. The first of these consists of the handle at the back of the fire-box, of 15-inch radius, and a 1-inch arm at right angles, making a leverage of 15 to 1. Through the second bell-crank, which has equal arms, the motion is conveyed to the stop-valve. The supply of steam to the cylinder is regulated by a throttle-valve, which works in a cylindrical necking 2 inches in diameter, formed in the steam-pipe between the boiler and the stop-valve. It is controlled by the governor through a lever acting on an arm fixed on the valve-spindle, the details of which are shown in figs. 794. The governor is an ordinary governor having two 4-inch balls on 9-inch arms, and a central weight, 5 inches in diameter, in one piece with the grooved sleeve on the spindle. The spindle is ⅞ inch in diameter, and makes 110 turns per minute. It is driven by a band from the main shaft, with a vertical pulley and bevel wheels in the governor-bracket.



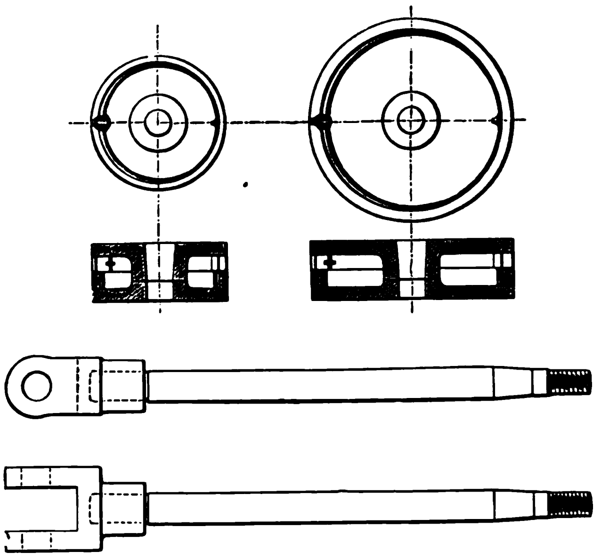
Figs. 794.—Garrett's Portable Engine: Governor. Scale 1/10th.

The slide-valves are driven by eccentrics, 7⅜ inches in diameter, with 2⅜ inches of travel. The outside lap is $^{13}/_{16}$ inch, the lead ⅛ inch. There is "negative" lap, or inside lead, ⅛ inch. The valve-spindles are of steel.

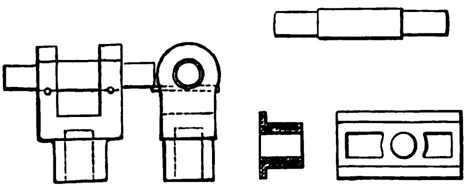
The glands and linings of the stuffing-boxes are of phosphor-bronze.

The exhaust steam is discharged through a 2¼-inch wrought-iron pipe along the top of the boiler into the chimney, where it is discharged through a 1¾-inch orifice.

The pistons, figs. 795, are of cast iron, 3 inches thick, of ⅝-inch metal, with two packing-rings, ⅞ inch thick, each cut at one place, and tightened by a circular spring and glut, in the manner already explained for the typical engine, page 403. The piston-rods, figs. 795, are of Siemens-Martin steel; they are 1⅝ inches in diameter, let with a taper of ¼ inch in 2 inches through the pistons, and fastened by a nut. They are reduced cylindrically at the other ends to a diameter of 1½ inches, and are cottered into the crossheads, figs. 795 and 796. These are forked to carry the gudgeons, which offer a journal 1½ inches in diameter, and 2¼ inches long. The gudgeons are secured to the crossheads by means of taper pins. They are reduced at the ends to 1¼ inches in diameter to take the two guide-blocks, which are of cast iron, 6½ inches in length. The blocks are divided unequally by the gudgeons, the centres being nearer to the outer ends of the blocks, thus placed for convenience of adjustment of the gland when the crosshead is at the cylinder end of its stroke. The guide-bars, figs. 797, are of cast iron, 1¾ inches wide, ⅞ inch thick, with a stiffening flange. They are in two pairs, one pair to each cylinder, fixed 2¼ inches apart, at one end to the cylinder-covers, and at the other to two cast-iron brackets, figs. 797, bolted to the boiler, notched to receive the bars. The bolts are ⅝ inch in diameter.



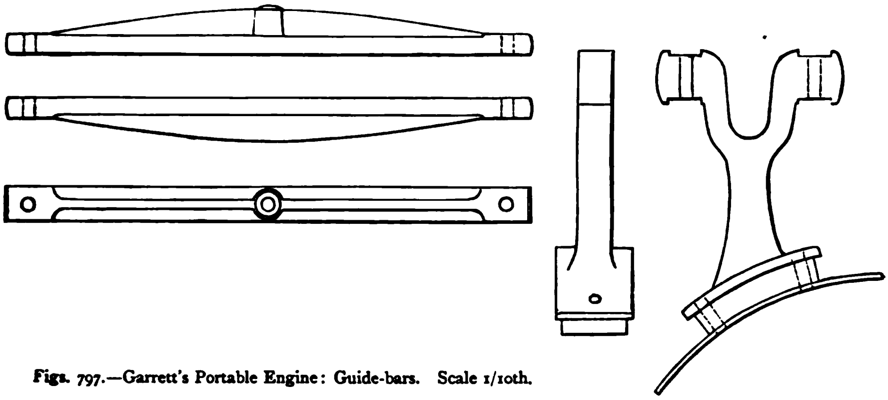
Figs. 795.—Garrett's Portable Engine: Pistons and Piston-rods. Scale 1/10th.



Figs. 796.—Garrett's Portable Engine: Crossheads and Slides. Scale 1/10th.

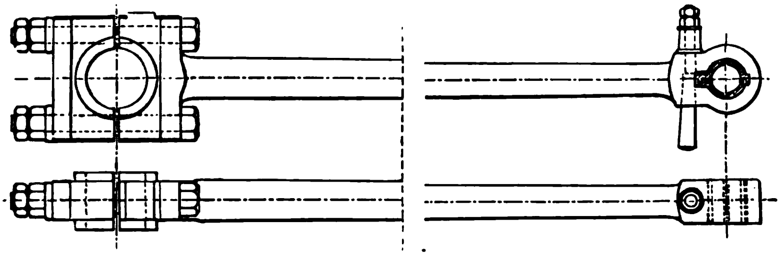
The connecting-rods, figs. 798, are of steel, 4 feet long, or 9.6 times the length of the crank. The bearings are 1½ inches in diameter, 2¼ inches long at the crosshead end; and 3⅛ inches in diameter, 3 inches long at the crank end. The body of each rod is round, tapering from 1⅝ inches in diameter at the smaller end to 2⅛ inches at the larger. The smaller end is forged solid, slotted out for the brasses, which are fixed with a cotter secured by double-nuts. The larger end is on the cap-and-bolts system, with two flat-faced brasses, and ⅞-inch bolts fixed with double-nuts.

The main or crank shaft, figs. 799, is of steel, bent to form two cranks out of one piece. It is 3⅛ inches in diameter at the straight portions and



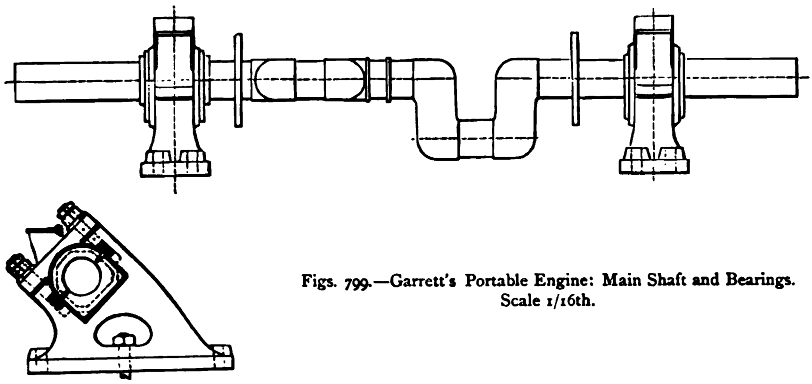
Figs. 797.—Garrett's Portable Engine: Guide-bars. Scale 1/10th.

at the crank-pins, and is 5½ feet long over all. The cranks are formed to a radius of 5 inches, with rounded limbs 3⅜ inches in diameter. The



Figs. 798.—Garrett's Portable Engine: Connecting-rods. Scale 1/10th.

crank-pin bearings are 2½ inches long for the first cylinder, and 3 inches for the second cylinder. The main bearings are of phosphor-bronze. They



Figs. 799.—Garrett's Portable Engine: Main Shaft and Bearings. Scale 1/16th.

are 5 inches long, for one of which only, next to the first cylinder, collars are formed on the shaft. The fly-wheel is of cast iron, 4 feet in diameter, 8 inches wide at the rim. The nave, fig. 800, is 4 inches wide an

in diameter. The wheel is keyed on the end of the shaft next to the collar-bearing, and the key is secured by a safety-pin through the shaft. A 3-feet pulley, 8 inches wide, is fixed on the other end of the shaft. The plummer-blocks, figs. 799, of cast iron, are bolted to a cast-iron saddle, of ½-inch metal, on the barrel of the boiler, figs. 801, each with five ⅞-inch bolts and nuts. They are inclined backwards at 45°. The cap is held by two ⅞-inch cotter-bolts with double-nuts. The saddle is fixed with twenty-four ¾-inch bolts and nuts.

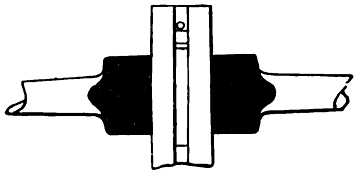
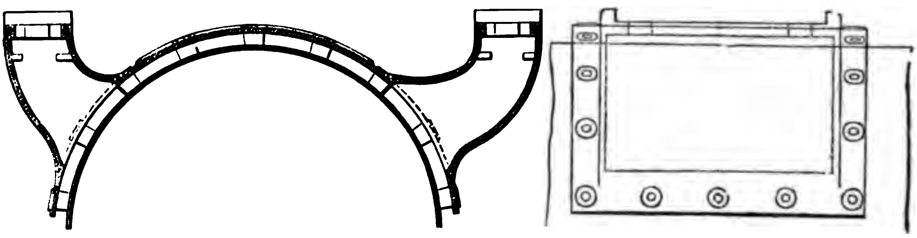


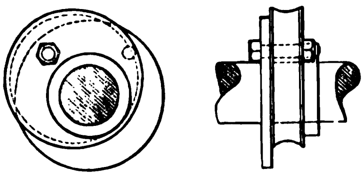
Fig. 800.—Garrett's Portable Engine: Centre of Fly-wheel. Scale 1/10th.

The eccentrics are loose on the main shaft, and are bolted to discs which



Figs. 801.—Garrett's Portable Engine: Saddle for Main Bearings. Scale 1/16th.

are forged solid on the shaft, as shown in figs. 802. The discs have two holes, one to fix the position of the eccentric for forward movement, and the other for convenience of reversal. If it is desired to provide for varying the expansion, this can be done by making suitable holes intermediately in the discs. But this mode of varying expansion necessitates the employment of a special eccentric having an oval hole in the boss, in order by giving a constant lead to avoid distortion of the indicator diagram. For the sake of "evenness of turning," Messrs. Garrett prefer to cut off at half-stroke in each cylinder. The variation of the initial pressure of the steam, from 120 lbs. to 80 lbs. per square inch, by means of the throttle-valve affords, in their opinion, the most satisfactory government of their compound portable engine.



Figs. 802.—Garrett's Portable Engine: Eccentric. Scale 1/10th.

The feed-pump, fig. 803, is of phosphor-bronze. It is of the usual three-valve type, as already described, page 406. It is fastened to one side of the boiler, and is worked b centric on the main shaft. It is having a ram 1 15/16 inches in diameter, with a stroke of 2⅜ are one suction-valve, and two successive delivery-valves, 1

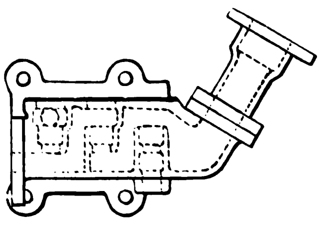


Fig. 803.—Garrett's Portable Engine: Feed-pump. Scale 1/10th.

with a lift of ¼ inch. The water is delivered to the boiler through a ⅞-inch pipe. The pump is regulated by means of the regulating valve to serve the boiler continuously in connection with the water-heater. When the water is not delivered to the boiler, it is forced through a nozzle, shown in section in fig. 804; creating a partial vacuum, and so inducing the steam from the exhaust-pipe through the annular space surrounding the nozzle, when the water is returned in combination with it to the feed-water tank.

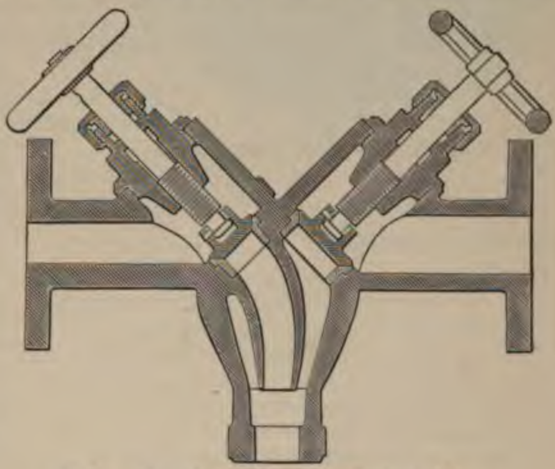


Fig. 804.—Garrett's Portable Engine: Feed-water Heater.

The engine is carried on four wheels, 4½ feet and 3½ feet in diameter, 9 feet 2 inches apart between the centres. They are 8 inches wide at the tyre. The spokes, ⅞ inch in diameter, are made separately, with a cast-iron nave and a cast-iron rim, 1 inch thick at the middle and ⅝ inch at the edges.

The weight of the boiler is 33½ cwts.; that of the engine, without the driving pulley, 41¼ cwts.; that of the carriage work 26¾ cwts.; together 5 tons 1½ cwts. The fly-wheel weighs 6 cwts. When filled with water to the ordinary working level, the total weight is 5 tons 16¾ cwts.

The working pressure is from 100 lbs. to 120 lbs. per square inch; and the hydraulic test-pressure for the boiler is 250 lbs. per square inch. The cylinders of compound portable engines sent to France, Germany, and Austria, are tested by hydraulic power to a pressure of 200 lbs. per square inch by the government officials there. The minimum factor of safety in the proportioning of the engine and boiler is 6. The regular speed is 180 turns, or 300 feet of piston per minute, developing 30 indicator horse-power.

This engine was tested by the constructors on the 10th and 13th March, 1883. The leading results of the tests are given in next page. On the second day the fire-grate was reduced by brickwork:—13½ inches wide against the tube-plate, and 1¼ inches wide at each side, 5½ inches high, leaving an open space of fire-grate 3.8 square feet in area, or $^1/_{41}$ part of the heating surface.

The mean dynametrical or break horse-power is 87.4 per cent of the ...tor power, showing 12.6 per cent frictional resistance.

...ay be explained with respect to the power developed—at the first ...nstance—that the average effective pressure was 31.56 lbs. per ...n the first piston, and 20.61 lbs. on the second piston. The

"A" Compound Portable Engine (Messrs. R. Garrett & Sons).

Date of Trial	March 10, 1883.	March 13, 1883.
Duration of trial	3 h. 19 m.	3 h. 32½ m.
Area of fire-grate	6.3 sq. feet.	3.8 sq. feet.
Pressure of steam in boiler per square inch	100 lbs.	100 lbs.
Coal consumed (Llangennech)	294½ lbs.	296 lbs.
Do. per hour	88.70 „	83.62 „
Do. do. per sq. foot of fire-grate	14.09 „	22.01 „
Temperature of feed-water, cold	54° F.	57°.5
Do. do. in tub, heated by exhaust steam	125°	126°
Water evaporated	34.3 cu. ft. 2139.0 lbs.[1]	35.8 cu. ft. 2236 lbs.[1]
Do. per hour	10.33 cu. ft.	10.78 cu. ft.
Do. do. per sq. ft. of fire-grate	1.64 „	2.83 „
Do. per pound of coal	7.26 lbs.	7.55 lbs.
Do. do. do. from and at 212° F.	8.20 lbs.	8.53 lbs.
Revolutions per minute	192.4 turns.	176.0 turns.
Indicator horse-power	29.14 H.P.	30.08 H.P.
Dynametrical horse-power	25.65 „	26.13 „
Do. do. per cent of indicator power	88 per cent.	86.8 per cent.
Coal per indicator horse-power per hour	3.04 lbs.	2.79 lbs.
Do. per dynametrical do. do.	3.46 „	3.19 „
Water per indicator do. do.	22.13 „	21.49 „
Do. per dynametrical do. do.	25.14 „	24.16 „

products of these by the respective areas of pistons are the total average pressures on the pistons, namely 1214.586 lbs. and 1784.62 lbs.: together 2999.206 lbs. The stroke is 10 inches, or $^{10}/_{12}$ foot; and the indicator horse-power is

$$\frac{2999.206 \times 10 \text{ in.} \times (192.4 \text{ turns} \times 2)}{12 \times 33000} = 29.14 \text{ I.H.P.}$$

as stated in the table. Of this power, 11.80 horse-power is developed in the first cylinder, and 17.34 in the second cylinder.

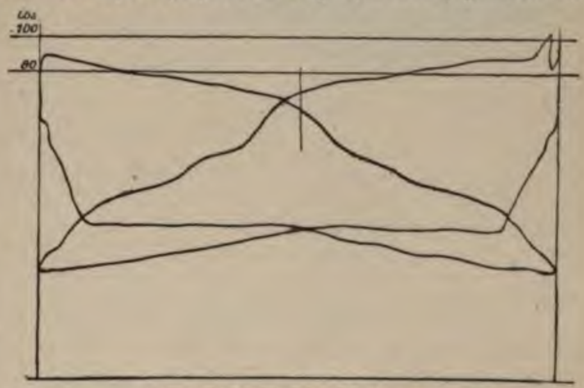
The well-established result of reducing the area of the fire-grate in increasing evaporative efficiency is exemplified in this case:—

Area of fire-grate	6.3 sq. ft.	3.8 sq. ft.
Coal per hour per square foot of grate	14.09 lbs.	22.01 lbs.
Water per pound of coal, from and at 212° F.,	8.20 „	8.53 „

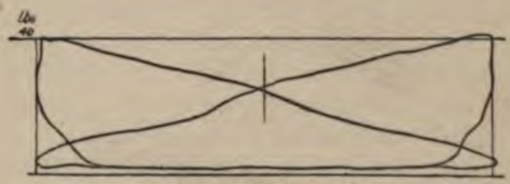
The water, as steam, used is 21½ pounds per indicator horse-power per hour. Ten sets of indicator diagrams were taken at regular intervals during each trial. According to the average of these for the first day, of which samples are shown in figs. 805, the average pressures at cut-off in the first

[1] Including 135.5 pounds and 136 pounds respectively of condensed steam through the water-heater.

cylinder were 83.1 lbs., and 79.17 lbs. per square inch above the atmosphere, for the right-hand side of the diagrams, and the left-hand or piston-rod side, respectively, the mean pressure having been 81.4 lbs. per square inch above the atmosphere, or say (81.4+15=) 96.4 lbs. absolute pressure. The volume cut off, ignoring the volume of the piston-rod, including clearance, was .1421 cubic foot for each stroke; or (.1421 × 2 × 192.4 × 60=) 3280 cubic feet per hour. Multiplied by .2228 pound, the weight per cubic foot, the weight of steam cut off per hour was (3280 × .2228 =) 730.8 pounds. Steam was shut in by compression at a pressure of 42 lbs. per square inch above the atmosphere, or (42 + 15 =) 57 lbs. absolute pressure. The period of compression was 1 inch of the stroke, and the volume shut in per stroke was .053 cubic foot. The volume per hour was 122.37 cubic feet; and the weight was (122.37 × .1364 lb. =) 166.9 pounds. The average final pressure by expansion to 7/8ths of the stroke was 49 lbs. per square inch above the atmosphere, or (49+15=) 64 lbs. absolute pressure; and the weight of expanded steam per hour was 789.6 pounds.



First Cylinder: Cut-off at Half-stroke.



Second Cylinder: Cut-off at Half-stroke.

Figs. 805.—Garrett's Compound Portable Engine: Indicator Diagrams.

In the second cylinder the pressures at cut-off averaged 25.2 lbs. per square inch above the atmosphere, or 40.2 lbs. absolute pressure, giving, at the rate of .0978 pound per cubic foot, 665.4 pounds of steam cut off per hour. The average pressure by expansion at the end of the stroke was 7 lbs. per square inch above the atmosphere, or 22 lbs. absolute pressure, giving at the rate of .0555 pound per cubic foot, 755.1 pounds of expanded steam per hour. The exhaust steam was shut in for the last inch of the return stroke, at 5 lbs. pressure per square inch, or 20 lbs. absolute pressure, weighing .0507 pound per cubic foot, and making 110.3 pounds of steam intercepted per hour.

Comparing the actual ratios of expansion and the ratios of absolute pressure:—

	1st Cylinder.	2d Cylinder.
Actual ratio of expansion	1 to 1.78.	1 to 1.85.
Absolute pressures inversely	64 lbs. to 96.4 lbs. 1 to 1.51.	22 lbs. to 40.2 lbs. 1 to 1.83.

The weights of steam consumed per hour, according to the evidence of the indicator diagrams, above detailed, are as follows:—

Steam per Hour, as per Indicator.

Cut-off.	Expanded.		Difference.
1st Cylinder........ 730.8 lbs.		789.6 lbs.	58.8 lbs., or 7.4 pr. cent of expanded steam.
	Compressed...	166.9 „	
	Net used	622.7 „	
2d Cylinder .... 665.4 lbs.		755.1 lbs.	
	Compressed...	110.3 „	89.7 lbs., or 11.9 pr. cent of expanded steam.
	Net used	644.8 „	
Feed-water supplied to the boiler (2139 lbs. ÷ 3.32 hours =)...	....	644.3 lbs.	

Herein is presented the usual phenomenon of a greater weight of sensible steam at the end of the stroke than at the point of cut-off, resulting from initial condensation of steam during admission, and re-evaporation during expansion. The excess weight is 7.4 per cent in the first cylinder, and 11.9 per cent in the second, the steam being cut off in each at half-stroke. That the percentage of condensation in the second cylinder should be greater than that in the first is readily explained by the greater range of temperature in the second cylinder, or the difference of temperatures of the initial steam and the exhaust steam. They range between 325° and 289° in the first cylinder, and between 287° and 220° in the second cylinder; or through 36° and 67° respectively.

To compare, finally, the net weights of expanded steam consumed, according to the indicator, with the weight of feed-water supplied, they are:—

First cylinder, steam	622.7 lbs.	per hour.
Second do., do.	644.8 „	„
Feed-water supplied	644.3 „	„

The identity of the weight of steam indicated in the second cylinder with the weight of feed-water supplied is noteworthy; and it is greater than that of the expanded steam indicated in the first cylinder, which is only 97 per cent of the feed-water. The deficiency is not very considerable; but, such as it is, it is occasioned by the want of space through which by expansion and re-evaporation, the steam could be entirely recovered. The measurement of the expanded steam was taken at a point one-eighth of the stroke from the end. If it could have been correctly reckoned as at the end of the stroke, no doubt the whole of the steam would have been brought into evidence. As it is, a portion of the condensation-water was flashed into steam when the port was opened for the exhaust.

Of course, a part of the steam in the work of expansion is finally reduced to water, and the equality of the net indicated steam consumed in the

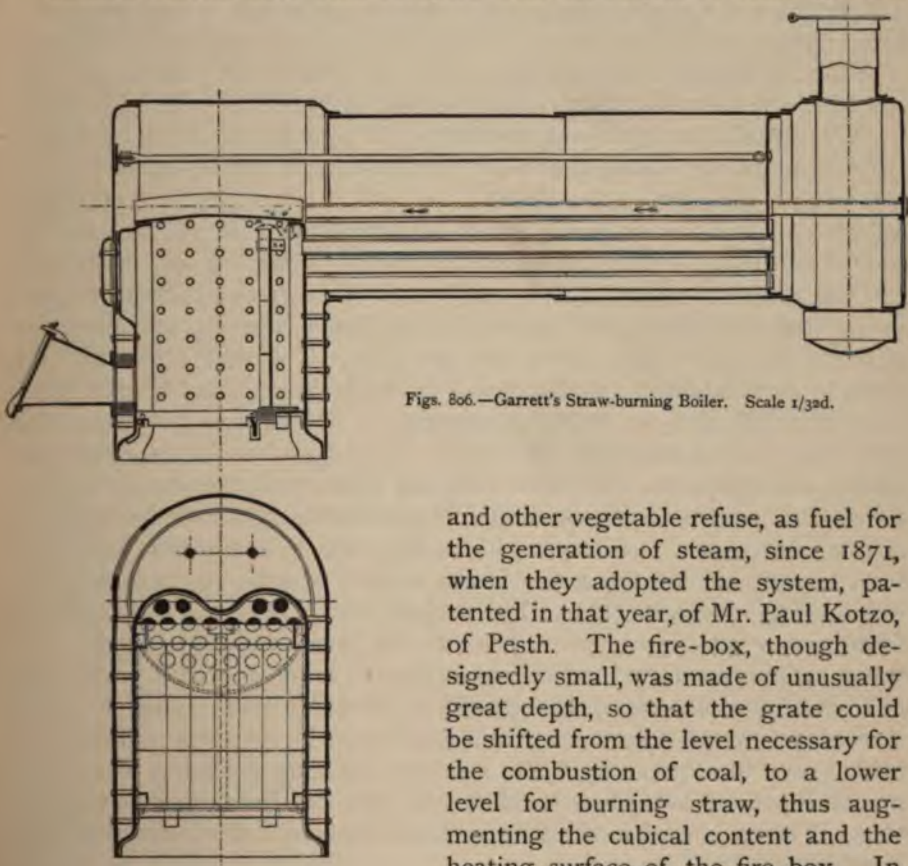
second cylinder to the feed-water supplied, points to the slight discrepancy caused by the want of allowance for the space occupied by the piston-rod, or to some slight error of observation. But the comparatively excellent performance of the engine in point of efficiency of steam, corroborates the deduction that the absence of a steam-jacket for cylinders in which the steam is admitted for half the stroke, is not sensibly disadvantageous.

The deduction is also supported by the table No. 101, page 474, vol. i., showing that only 4.3 per cent of the steam is condensed on admission, when cut off at half-stroke.

Chapter LII.—STRAW-BURNING PORTABLE STEAM BOILER.

CONSTRUCTED BY MESSRS. R. GARRETT & SONS.

Messrs. Garrett have been occupied with the subject of utilizing straw and other vegetable refuse, as fuel for the generation of steam, since 1871, when they adopted the system, patented in that year, of Mr. Paul Kotzo, of Pesth. The fire-box, though designedly small, was made of unusually great depth, so that the grate could be shifted from the level necessary for the combustion of coal, to a lower level for burning straw, thus augmenting the cubical content and the heating surface of the fire-box. In addition, a preliminary stoking and heating chamber or hopper was fastened to the back of the fire-box. in



Figs. 806.—Garrett's Straw-burning Boiler. Scale 1/32d.

which the straw could be thoroughly dried and heated, preparatory to its being pushed into the fire-box. As it was pushed in, it ignited instantly, almost explosively. The area of fire-grate was only 4.2 square feet for an engine of 8 horse-power; and the heating surface amounted to 158 square feet. By the results of trials of this engine in 1875, 1.6 pounds of water was evaporated per pound of English straw.

The straw-burning boiler now constructed by Messrs. Garrett, is shown in figs. 806. The feeding hopper or mouth-piece is retained, and a fire-bridge, or partition of fire-tiles, is run up in front of the tube-plate, reaching nearly to the roof of the fire-box, over which the burnt gases are passed on their way to the flue-tubes. On turning the partition, the gases are met by one or more currents of air for combustion introduced from the front of the boiler through the four uppermost flue-tubes, in which it is heated on its way. But they can be converted into flue-tubes, when desired. The fire-box is 2 feet 4½ inches square, reduced 8 inches in length to 20½ inches by the partition, which is 2½ inches thick, and stands 5¾ inches clear of the tube-plate. The fire-grate has 3.9 square feet of area. There are 27 flue-tubes 2½ inches in diameter outside, 6½ feet long. The heating surface of the fire-box is 34 square feet, and that of the tubes is 116 square feet; together, 150 square feet, or 37½ times the grate-area.

When the boiler is at work the hopper is kept full of straw, in order to prevent an undue indraught of air. The fire-bridge is designed to promote the mixture and combustion of the gases, and it intercepts and collects the siliceous deposit or straw-ash, which otherwise operates and accumulates very disadvantageously upon the surfaces of the tube-plate and the tubes.

The results of twelve trials of simple and of compound portable engines, using coal and straw as fuels, made by Messrs. Garrett, are abstracted and rearranged in tables Nos. 168 and 169. The first table, No. 168, gives leading data and descriptions of the engines submitted to trial, which were of 10, 8, and 6 nominal horse-power. The second table, No. 169, gives the leading results of the trials. The straw-burning engines, both simple and compound, were tried with and without the fire-bridge and air-tubes, with coal and with straw as fuel, alternately, and with two different sizes of fire-grate. Ordinary coal-burning engines, in addition, were tried for comparison. Of these, the Derby engine, it may be explained, was exhibited at Derby, in 1881.[1] The bottom of the fire-box is double-plated, forming a water-space, which serves as the bottom of the ash-pit. The water-space is connected to the crown-plate by a 5-inch vertical water-tube, in front of the tube-plate, through which circulation takes place. On each side of the water-tube a fire-brick diaphragm is constructed, forming a bridge over the top of which the burning gases are delivered, where they meet a supply of heated air which arrives from the front through six flue-tubes. The coals used were Llangennech anthracite, and Hucknall seconds Northamptonshire steam coal.

[1] This portable engine is described and illustrated [illegible] *[illegible]ineer*, July 15, 1881; pages 39, 41.

The steam was cut off in each cylinder of the compound engines and in the simple cylinders, at half-stroke. The style of the diagrams of the compound engines is exemplified by figs. 805, page 431; and that of the diagram from the simple engines is typified by the annexed figure 807, which was taken from a 6-horse-power engine, at a speed of 180 turns, or 300 feet of piston per minute, indicating 20.27 horse-power.

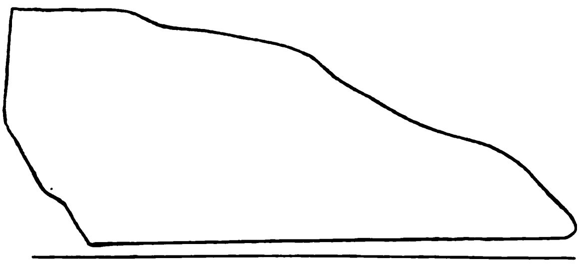


Fig. 807.—Garrett's Simple Portable Engine of 6 Horse-power: Indicator Diagram. Vertical Scale of Pressure, 56 lbs. per inch high.

Summarizing the waters evaporated from and at 212° F. per pound of fuel, in Nos. 1 to 8 trials, they are as follows:—

Comparative Evaporative Efficiency of Coal and Straw.

Water per lb. of Coal.			Water per lb. of Straw.	
No. 1, L. coal...	8.17 lbs.	8.38	No. 3	2.37 lbs.
No. 2, do. ...	8.59 „		No. 4	2.75 „
No. 5, H. coal..	6.55 „	6.59	No. 7	2.09 „
No. 6, do. ..	6.63 „		No. 8	2.54 „
Averages......	7.48 „		Averages......	2.44 „

Showing that an average of about 2½ pounds of water was evaporated per pound of straw—one-third of the water, about 7½ pounds, evaporated per pound of coal. Correspondingly, upwards of three times as much straw was consumed per hour as of coal. But the combustion of straw is very rapid, and no augmentation of fire-grate appears to be needful for its combustion, although it is much more bulky than coal.

The influence of the area of fire-grate, altered in the same boiler, on the evaporative efficiency, is shown by a rearrangement of the results of Nos. 1 to 8 trials, thus:—

Comparative Evaporative Efficiency for Different Areas of Fire-grate.

Area of grate, 8 *square feet.*	*Area of grate,* 6.3 *square feet.*
No. 1, coal....8.17 lbs. water per lb.	No. 2, coal....8.59 lbs. water per lb.
No. 3, straw...2.37 „ „ „	No. 4, straw...2.75 „ „ „
Area of grate, 5.5 *square feet.*	*Area of grate,* 3.9 *square feet.*
No. 5, coal....6.55 lbs. water per lb.	No. 6, coal....6.63 lbs. water per lb.
No. 7, straw...2.09 „ „ „	No. 8, straw...2.54 „ „ „
Average......4.80 lbs.	Average......5.13 lbs.
Augmentation by reducing grate-area, .33 lb., or 7 per cent.	

Table No. 168.—Leading Data of Simple and Compound Portable Engines, using Straw and Coal as Fuels, by Messrs. R. Garrett & Sons.

No. of Trial.	Nominal Horse-power.	Simple or Compound.	Cylinders. Diameter of 1st Cyl.	Cylinders. Diameter of 2d Cyl.	Cylinders. Ratio of Areas.	Cylinders. Stroke.	Area of Fire-grate.	Heating Surface. Fire-box.	Heating Surface. Tubes.	Heating Surface. Total.	Ratio of Heating Surface to Fire-grate.	Description of Boiler.
No.	H.P.		inches.	inches.	ratio.	inches.	sq. feet.	sq. feet.	sq. feet.	sq. feet.	ratio.	
1	10	Compound.	7¾	11½	2.20	10	8	46	155	201	25.1	Straw-burner: no fire-bridge; no air-tubes; new boiler, primed a little.
2	,,	,,	,,	,,	,,	,,	6.3	,,	,,	,,	32.0	Straw-burner: fire-bridge and air-tubes.
3	,,	,,	,,	,,	,,	,,	8	,,	,,	,,	25.1	Straw-burner: no fire-bridge; no air-tubes.
4	,,	,,	,,	,,	,,	,,	6.3	,,	,,	,,	32.0	Straw-burner: fire-bridge and air-tubes.
5	6	Simple.	7¾	—	—	10	5.5	34	116	150	27.3	Straw-burner: no fire-bridge; no air-tubes; new boiler, primed a little.
6	,,	,,	,,	—	—	,,	3.9	,,	,,	,,	38.5	Straw-burner: fire-bridge (improved), and air-tubes.
7	,,	,,	,,	—	—	,,	5.5	,,	,,	,,	27.3	Straw-burner: no fire-bridge; no air-tubes.
	,,	,,	,,	—	—	,,	3.9	,,	,,	,,	38.5	Straw-burner: fire-bridge and air-tubes.
	8	,,	9	—	—	12	4.2	22	116	138	33.0	Ordinary coal-burner: no fire-bridge; no air-tubes.
	,,	,,	,,	—	—	,,	3	,,	,,	,,	46	Ordinary coal-burner: fire-bridge and air-tubes.
	10	Compound.	7¾	11½	2.20	10	8	—	—	175	21.9	Colonial boiler: no fire-bridge; no air-tubes.
	,,	,,	,,	,,	,,	,,	9.4	—	—	,,	18.6	Derby engine: fire-bridge and air-tubes.

Table No. 169.—Results of Comparative Trials of Simple and Compound Portable Engines, using Straw and Coal as Fuels, by Messrs. R. Garrett & Sons, Leiston.

No. of Trial.	Date of Trial.	Nominal Horse-power.	Simple or Compound.	Duration of Trial.	Pressure of Steam per Square Inch.	Fuel Consumed.				Water Evaporated.							Revolutions per Minute.	Dynametrical Horse-power.	Fuel per Horse-power per Hour.	Water per Horse-power per Hour.
						Coal or Straw.	Total.	Per Hour.	Per Hour per Square Foot of Fire-grate.	Temperature.	Total Evaporated.		Per Hour.	Per Hour per Square Foot of Fire-grate.	Per Pound of Fuel.	Per Pound of Fuel, from and at 212°.				
No.		N.H.P.		h. m.	lbs.		pounds.	pounds.	pounds.	Fahr.	lbs.	cu. ft.	cu. ft.	cu. ft.	pounds.	pounds.	turns.	H.P.	pounds.	pounds.
1	1881. Mar. 30	10	Compound	4 20	80	L. coal	370	85.4	10.7	109°	2655	42.9	9.91	1.24	7.17	8.17	181.3	24.18	3.54	25.4
2	Apr. 4	"	"	4 35	80	"	372	80.9	12.8	78	2731	43.9	9.54	1.51	7.34	8.59	188.4	25.13	3.23	23.7
3	Mar. 29	"	"	3 52	80	Straw	1120	290.2	36.3	108	2333	37.7	9.77	1.22	2.08	2.37	176.6	23.64	12.3	25.5
4	May 2	"	"	4 18	80	"	1120	262.3	41.6	95	2676	43.1	10.10	1.60	2.39	2.75	183.8	24.50	10.6	25.3
5	May 13	6	Simple	2 36	80	H. coal	251½	96.6	17.6	145	1496	24.4	9.39	1.71	5.95	6.55	180.5	16.37	5.92	35.2
6	May 20	"	"	2 59	80	"	256	85.3	21.9	153	1544	25.3	8.43	2.16	6.03	6.63	181.5	16.46	5.22	31.5
7	May 14	"	"	2 39	80	Straw	756	285.3	51.8	139	1437	23.4	8.83	1.61	1.90	2.09	180.8	16.39	17.4	33.1
8	May 21	"	"	3 14	80	"	756	236.0	60.5	151	1748	28.6	8.85	2.27	2.31	2.54	180.7	16.38	14.2	33.0
9	July 20	8	Simple	2 30	80	H. coal	309½	123.8	29.5	153	2012	33.0	13.20	3.14	6.50	7.15	162	22.80	5.43	35.3
10	July 26	"	"	2 38	80	"	308½	117.3	39.1	153	2145	35.2	13.38	4.46	6.95	7.64	162	22.80	5.14	34.6
11	1880. Nov. 19	10	Compound	3 40	100	L. coal	370	100.8	12.6	90	2543	40.9	11.14	1.39	6.87	7.97	174	28.3	3.56	24.4
12	1881. Aug. 4	"	"	3 48	100	"	372	97.9	10.4	161	2770	45.4	12.00	1.28	7.44	8.18	188	30.7	3.18	23.8

Note to Table.—"L. coal" signifies Llangennech Anthracite; "H. coal" signifies Hucknall Seconds Northamptonshire steam coal.

The apparent advantage of the use of the straw-burning apparatus in Nos. 4 and 8 trials, as here shown, averages 7 per cent as against the use of the plain fire-box in Nos. 3 and 7.

The tabulated results show a marked contrast between the economic performance of the compound and simple portable engines, in the last column—of the water consumed per dynametrical horse-power per hour. Thus:—

Average Consumption of Water as Steam per Dynametrical Horse-power.

Compound engines,	Nos. 1 to 4 trials	.... 25 lbs.	per H.P.
Simple do.	Nos. 5 to 8 „	.... 33.2 „	„

showing a difference of 8.2 pounds of water per horse-power in favour of the compound engine, or about one-fourth of the water consumed by the simple engine. The first cylinder of the compound engine is of the same diameter, 7¾ inches, as the simple cylinder, and the economic effect is clearly traceable to the addition of the second cylinder, by means of which the expansion of the steam was about doubled. In the simple cylinder the nominal expansion was to double the initial volume; and, in the compound cylinders, to four volumes. It is probable that the economic results would not have been materially affected, if steam-jackets had been applied to the cylinders, supposing the same degrees of expansion.

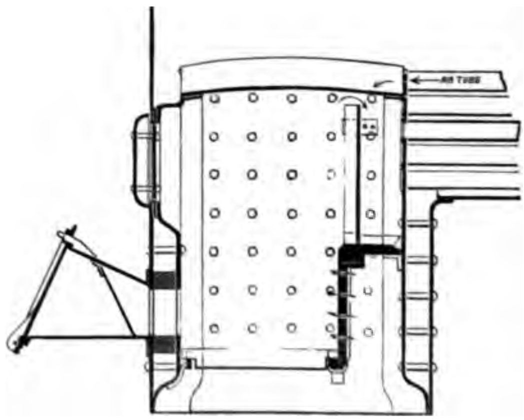


Fig. 808.—Garrett's Straw-burning Boiler, for burning chopped straw. Scale 1/32d.

The consumption of coal and of straw per horse-power per hour average for the compound engine respectively 3.39 pounds and 11.4 pounds; and for the simple engine 5.57 pounds and 15.8 pounds.

It is shown too that the dynametrical horse-power developed in the compound cylinders is about one-half more than in the simple cylinder, the horse-power averaging respectively 24.36 H.P. and 16.40 H.P.

A modification of the straw-burning fire-box, fig. 808, is employed by Messrs. Garrett & Sons, especially designed for burning "chopped straw," in countries where the straw is reduced, by means of a special apparatus in connection with the thrashing-machine, to the state of dry pulp for fodder. A perforated fireback below the folding doors of the bridge admits air over the back of the fire; and a flap-door is fitted inside the feed-hopper in order to prevent an excessive admission of air by the hopper, which is likely to happen, as the hopper cannot be maintained full of chopped straw as of long straw.

The perforated fireback gives good results also with long straw as fuel; but it is not necessary, as there is a free passage for air through the fuel.

CHAPTER LIII.

PORTABLE STEAM ENGINES AT THE SHOW OF THE ROYAL AGRICULTURAL SOCIETY AT NEWCASTLE-ON-TYNE, 1887.

The portable steam engines exhibited at Newcastle were partly simple or single-cylinder engines, and partly compound engines, as follows:—

SIMPLE ENGINES.	Fly-wheel.		Cylinders.		Steam Jacketed.
	Diameter.	Width.	Diameter.	Stroke.	
	inches.	inches.	inches.	inches.	
1. Alnwick Foundry Company....	48¾	6⅛	8¾	12	none.
2. E. Foden & Sons..................	53	6	7½	10	thoroughly.
3. Jeffery & Blackstone	40	5	5¾	9	none.
4. J. & H. Maclaren.................	60	7⅛	8½	15	thoroughly.
5. Davey, Paxman, & Co...........	60	7	9½	12	thoroughly.
6. E. Humphreys.....................	60	7½	10¼	14	cylinder only.
COMPOUND ENGINES.					
7. T. Cooper	48	6½	6 9	11 11	none.
8. E. Foden & Sons..................	53	6	4¾ 9½	10 10	thoroughly.
9. Davey, Paxman, & Co...........	60	6	5¾ 9¼	14 14	thoroughly.
10. J. & H. Maclaren................	60	7⅛	5¾ 9	15 15	thoroughly.
11. E. Humphreys.....................	60	7½	7½ 12	14 14	cylinder only.

The boiler of Jeffery & Blackstone's engine, No. 3, was vertical; the other boilers were of the usual locomotive type. Mr. E. Humphrey's compound engine was on the Woolf system. The engines were of 8 nominal horse-power, except No. 3, which was of 3 nominal horse-power.

No. 1 engine, single cylinder, is fitted with a single slide-valve of the Trick type, cutting off at 40 per cent. The fire-box casing was not lagged, and there was no feed-heater. The cylinder is fastened to the boiler by means of a pair of angle-irons riveted to the boiler, bolted to the cylinder.

In No. 2 engine, single cylinder, the slide-valve is worked by a link-motion, and carries a variable expansion-valve in its back, on Farcot's system, by frictional contact, until it is arrested, when the main valve travelling past it cuts off the steam. The travel is varied by means of a wedge which rises or falls under the influence of the governor, in a slot formed in the expansion valve-spindle. The feed-water is heated by

exhaust steam, and is further heated in the smoke-box by passing through a coil there. The boiler is controlled by a swivel damper in the chimney, instead of the usual ashpan damper.

In No. 3, vertical engine, single cylinder, the boiler was not lagged. The engine has an ordinary slide-valve; and the speed is regulated by a governor controlling a throttle-valve.

No. 4 engine, single cylinder, is fitted with a slide-valve having an expansion-valve on the back, controlled by a Hartnell governor on the main shaft. The main plummer-blocks are fastened each to a pair of plate brackets, connected by tie-rods to the cylinder. The feed-water is heated in a system of six copper tubes, arranged spirally in a chamber filled with exhaust steam. The shell of the boiler, and the fire-box, are of steel.

No. 5, single cylinder, is fitted with a slide-valve with an expansion-valve on the back, moved by means of a slotted link controlled by the governor. The link is moved by two eccentrics connected to the ends of it. The fire-box is fitted with eight Paxman water-tubes, springing from the sides of the fire-box a short distance above the grate, and curving upwards to the crown, where the upward currents are dispersed by deflectors.

No. 6 engine, single cylinder, has a plain slide-valve worked from an eccentric of variable travel, with a Hartnell-Turner governor on the main shaft. The feed-water is heated by the exhaust steam.

In No. 7, the first of the compound engines, each cylinder is fitted with a plain slide-valve worked by an eccentric. The intermediate receiver-space is 2.7 times the capacity of the first cylinder. The eccentrics are shifted for back gear by means of a frictional gripping gear. The engine is fitted with a Pickering governor, placed horizontally, acting on a throttle-valve.

No. 8, compound, is provided with a valve by means of which it may be worked either as a compound engine, or as two simple engines. The cylinders are each fitted with a slide-valve and link-motion, set independently; and the first cylinder is fitted, in addition, with a cut-off expansion-valve on the back of the main valve, as already noticed for the simple engine, No. 2. The feed-heater, also, is the same as for No. 2.

No. 9, compound, is constructed with side framing of channel iron, on the top of the boiler. The fire-box is without water-tubes as fitted in the simple engine, No. 5. The cylinders have slide-valves, and, for the first cylinder, a cut-off valve on the back of the main valve, controlled by the governor. The intermediate receiver-space is 1.4 times the capacity of the first cylinder. The boiler is of mild steel throughout.

No. 10, compound, is the same in design as the simple engine, No. 4, except that it has two cylinders. Accidentally, during the trial of No. 10, steam had to be shut off from the back-cover jacket of the first [illegible] the sight-feed lubricator on the first cylinder was inoperative [illegible] the eccentric strap overheated, and two crown stays of the [illegible] The intermediate receiver-space is 1.08 times the c[illegible] cylinder.

Table No. 170.—PORTABLE STEAM ENGINES, NEWCASTLE-ON-TYNE.—ROYAL AGRICULTURAL SHOW, 1887.

LEADING DIMENSIONS OF BOILERS, AND RESULTS OF THEIR PERFORMANCE.

	Simple Engines.						Compound Engines.				
ORDER NUMBER OF ENGINE............	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Description of boiler:—	loco.	loco.	vertical.	loco.	loco.	loco.	loco.	loco.	loco.	loco.	loco.
Tubes:—Number....................	24	76	27	51	53	30	22	76	53	51	30
Material....................	iron	steel	iron	iron	steel	iron	iron	steel	steel	iron	iron
Diameter outside.....ins.	2¾	1⅝	1¾	2	2	2⅝	2½	1⅝	2	2	2⅝
Length................ „	75	72	35	81¾	84¾	79¾	82½	66	84¾	81¾	79¾
Ordinary grate, area................ sq. ft.	6.68	3.35	2.60	6.7	5.73	5.93	3.67	3.35	5.37	6.70	5.93
Heating surface...................... „	148.7	211.5	49.0	218.1	238.1	167.7	124.9	192.2	226.7	218.1	167.7
Surface-ratio..................................	22.2	63.1	18.8	32.5	41.5	28.1	34.0	57.3	42.5	32.5	28.1
Trial grate, area...................... sq. ft.	5.98	2.63	2.60	3.39	4.69	4.18	3.67	2.63	4.32	3.39	4.18
Surface-ratio for trial........................	24.87	80.42	18.85	64.34	50.77	35.76	34.03	73.08	52.48	64.34	40.12
Fire-bars, thickness.................. inch	⅝	¾	⅞	⅜	½	½	¾	⅜	½	⅜	½
Air-spaces between bars, width ..... „	⅝	¼	7/16	3/16	¼	⅜	¼	¼	¼	3/16	⅜
Time on trial......................... h. m.	4 5	4 23½	4 11	4 23	4 23	4 1	4 5	4 21	4 28	4 24	2 26
Coal consumed per hour............. lbs.	98.93	31.48	27.01	45.57	44.03	87.39	63.43	34.14	37.61	46.02	102.3
Do. do. per square foot of grate.............................. „	16.54	11.97	10.40	13.44	9.39	20.91	17.28	12.98	8.71	13.57	24.47
Water evaporated per hour, including jacket-water...................... „	901	390	183.5	609	491	889.5	683	419	485	580	—
Water evaporated per pound of coal, from and at 212° F............ „	9.1	12.96	6.82	12.27	11.21	10.14	10.75	12.26	12.99	12.59	—

NOTE.—The jacket-water was returned to the boiler, and its equivalent value as ordinary feed-water is here taken for calculation.

No. 11, compound, is a Woolf engine, of which the cranks are placed 180° apart. The cylinders are fitted with three plate slide-valves, one of which admits steam to the first cylinder; one exhausts from the first to the second cylinder, and the third exhausts from the second cylinder. The valves are driven by eccentrics, one for each; and the governor acts on a throttle-valve.

Trials of the portable engines were conducted by the consulting engineers of the Society, Sir Frederick Bramwell and Mr. William Anderson; the results of which were published in their Official Report.

Table No. 171.—Portable Steam Engines, Newcastle-on-Tyne.

RESULTS OF PERFORMANCE OF BOILERS (LOCOMOTIVE TYPE), IN THE ORDER OF THE SURFACE-RATIOS.

Order Number of Engine.......	1.	7.	6.	Means of 5 and 9.	Means of 4 and 10.	Means of 2 and 8.
1. Number of tubes.........tubes	24	22	30	53	51	76
2. Diameter of tubes outside....................... inches	2¾	2½	2⅝	2	2	1⅝
3. Length of tubes......... „	75	82½	79¾	84¾	81¾	69
4. Heating surface......... sq. ft.	148.7	124.9	167.7	232.4	218.1	201.9
5. Area of grate for trial... „ „	5.98	3.67	4.18	4.50	3.39	2.63
6. Surface-ratio, for trial... ratio	24.87	34.03	35.76	51.63	64.34	76.75
7. Fuel consumed per square foot of fire-grate........... lbs.	16.54	17.28	20.91	9.05	13.50	12.48
8. Steam pressure in the boiler... lbs. per sq. inch	80	125	85	95 and 150	125 and 155	120 and 250
9. Water evaporated per hour.......................... lbs.	901	683	889.5	488	595	405
10. Water evaporated per pound of fuel from and at 212° F.................... „	9.10	10.75	10.14	12.10	12.43	12.61
11. Do. do. do. by formula (34), page 327............. „	8.90	9.14	9.09	10.92	11.06	12.40
12. Air utilized per pound of coal { „	10.17	11.11	11.245	11.15	11.36	10.97
.... { cu. ft.	142.4	155.5	157.3	156.12	158.5	153.65
13. Excess of air per pound of coal { lbs.	13.0	7.92	6.19	12.79	15.45	2.85
.... { cu. ft.	172.9	105.3	82.3	170.1	205.5	37.9
14. Temperature of the air... Fahrt.	68°	64°	64°	66°	72°	72°
15. Do. in the smoke-box....................... „	700°	680°	480°	397°	451°	412°

Some leading dimensions and quantities of the boilers, and results of their performance, are given in table No. 170. In some instances the fire-grates were reduced in area by bricking up, for the specific purpose of augmenting the efficiency and economy of fuel in the competitive trials, by the augmentation of the surface-ratio,—the ratio of the area of heating surface to the area of the fire-grate;—as already no tried at Cardiff, page 324, vol. i. Contrast, for exar ble engines, table No. 170, which have respecti :t

of heating surface; and 6.68 and 3.35 square feet of grate-area, yielding surface-ratios of 22.2 to 1, and 63.1 to 1. Yet the already exceptionally small grate, in the second engine, was reduced to 2.63 square feet in area, yielding the high surface-ratio 80.42 to 1. It was to be expected, therefore, that No. 2 boiler would show a much higher evaporative efficiency than No. 1:—12.96 pounds against 9.1 pounds per pound of coal. On the contrary, the boiler of greater evaporative efficiency evaporated considerably less than half the quantity of water per hour evaporated by the other.

To show the influence of surface-ratio on the performances of the boilers, dimensions and results for each boiler are arranged in table No. 171, in the order of the surface-ratios, line 6, the mean results for three pairs of boilers being taken. The quantity of water evaporated per pound of fuel, calculated by formula (34), page 327, vol. i., is entered in line 11. It is apparent that the actual evaporative efficiency, line 10, increases generally with the surface-ratios, line 6; but that the evaporative performance, line 9, decreases generally, although the last three heating surfaces are larger than the first three: showing that the greater heating surface was utilized, not for maximum performance, but for maximum efficiency. One feature is conspicuous, that the smaller grate-areas command the greater evaporative efficiencies.

With respect to the calculated efficiencies, line 11, they are, in some instances, considerably less than the observed efficiencies, line 10; at the same time, there is singular nearness to identity of the observed and calculated results in the first and last cases, at the two extremes of the scale of surface-ratios, thus:—

		Water per Pound of Coal from and at 212° F.	
	Surface-ratio.	Observed.	Calculated.
No. 1	24.87	9.1 lbs.	8.90 lbs.
Nos. 2 and 8	76.75	12.61 „	12.40 „

The intermediate divergencies are probably attributable to variations of the conditions of the engines and of the trials. For instance, Nos. 4 and 10 boilers are identical in every respect, and practically so in the rates of combustion; yet the evaporative efficiencies differ by .32 pound of water per pound of coal. Again, Nos. 5 and 9 are nearly identical in conditions, yet they differ in efficiency by 1.78 pounds of water. Nos. 2 and 8, similarly, differ in efficiency by .70 pound of water.

The temperatures in the smoke-box vary from 397° F. in Nos. 5 and 9 to 700° F. in No. 1. The excess of air varies from 37.9 cubic feet in Nos. 2 and 8 (Foden) to 172.9 cubic feet in No. 1 (Alnwick Foundry Company); or from 25 per cent to 122 per cent of the air that is chemically utilized. The unusually low percentage in the case of Messrs. Foden is due no doubt to the special care taken to close the damper when stoking. The damper, as before stated, is placed at the base of the chimney.

The coal used was Powell's Duffryn coal, of the following average composition, as reported by Messrs. Pattinson and Stead:—

	Per Cent.	Available.
Carbon	88.40	
Hydrogen	3.65	$-0.32 = 3.33$ H.
Oxygen	2.55	$= 0.32$ H $= 2.87$ H_2O (water).
Nitrogen	0.64	
Sulphur	0.76	$= 1.36$ per cent pyrites.
Ash	3.17	
Water	0.83	
	100.00	
Sulphur in ash	0.04	

Calorific Value in British Thermal Units.

Carbon	$.884 \times 14,544$ units	$= 12,856$ units.
Hydrogen	$.0333 \times 61,200$ "	$= 2,037$ "
Pyrites estimated at		47 "
Total per 1 lb. of coal		14,940 "
Weight of air required to burn 1 lb. of coal		11.38 lbs.

A sample of the wood used in lighting the fires was dried at a temperature of 380° F., and lost 22 per cent of moisture. The dry wood was composed as follows:—

	Per Cent.
Carbon	49.95
Oxygen	41.27
Hydrogen	6.00
Nitrogen	1.13
Ash	1.65
	100.00

With regard to the estimation of the quantity of feed-water supplied to each boiler, the water was derived from three sources: 1st, the water measured into the feed-tub; 2d, the water of condensation of the exhaust steam used in heating the feed-water; 3d, the water of condensation in the steam-jackets, which in most cases was drained back direct into the boiler. The first and second items were readily measurable and calculable; but the third item was simply approximated to on the assumption that, as in large engines with well-arranged steam-jackets, the condensation of steam in the jacket, when the expansion ratio is considerable, represents very nearly the quantity of heat converted into work. It has to be considered, of course, that the drainage from the jackets is at the temperature of the steam, and so corresponds to a smaller quantity evaporated from the standard feed temperature.

The consulting engineers prepared balance-sheets for each engine, in which the heat produced was entered on the debtor side, and the expenditure and losses on the creditor side. The b[illegible] Messrs. Davey, Paxman, & Co., is here subjoined in ta[illegible]

Table No. 172.—PORTABLE STEAM ENGINES, NEWCASTLE-ON-TYNE:—BALANCE-SHEET OF MESSRS. DAVEY, PAXMAN, & CO.'S SIMPLE PORTABLE STEAM ENGINE (No. 5).

Dr. *Cr.*

	Units.		Units.	Percentage.
To the heat developed in furnace :—		By heat expended :—		
In the combustion of wood:		1. In evaporating the water in the wood and heating its steam to 385° F., the temperature of the escaping products	9,557	.32
From carbon	79,331			
From hydrogen	4,816			
In the combustion of coal:		2. In heating the wood and the air required for its combustion from 70° to 385°	3,884	.13
From carbon	2,481,400			
From hydrogen	337,475	3. In evaporating the water in the coal and heating its steam to 385°	8,374	.29
From sulphur	9,071			
		4. In heating the coal and the air required for its combustion from 70° to 385°	129,321	4.44
		5. In displacing the atmosphere by the products of combustion of the wood and the coal, with the air needed for their combustion	53,394	1.83
		6. In heating the excess of air	130,980	6.34
		In displacing the atmosphere by the excess of air	53,509	
		7. In evaporating the water in the boiler	2,090,300	71.78
		8. In radiation and convection	271,307	9.32
		9. In ashes and unconsumed fuel	53,915	1.85
		10. Unaccounted for	107,552	3.70
	2,912,093		2,912,093	100.00

The leading results of performance of the engines proper are given in table No. 173. The lowest consumption of steam is that of Davey, Paxman, & Co.'s engine, 21.30 pounds per indicator horse-power. The economy effected by compounding compared with simple engines of like construction was in three cases as follows:—

		Water per I.H.P.		Water per I.H.P.	Economy.
Foden	No. 2 simple	28.10 lbs.	No. 8 compound	22.48 lbs.	20 per cent.
Paxman	No. 5 "	24.77 "	No. 9 "	21.30 "	14 "
Maclaren	No. 4 "	25.99 "	No. 10 "	24.15 "	7 "

The break horse-power in the simple engines, not including Nos. 1, 3, and 4, is from 82 to 85 per cent of the indicator power; and that of the compound engines from 82 to 94 per cent. Apparently, the internal resistance is not increased by compounding.

The engineers show, in an ingeniously constructed table, here reproduced, No. 174, by comparison with the best performance at the Cardiff show, the economical effect of augmenting the steam pressure, and utilizi

Table No. 173.—Portable Steam Engines, Newcastle-on-Tyne.—Results of Performance of the Engine Proper.

	Simple Engines.						Compound Engines.				
Order Number of Engine..............	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Effective pressure in boiler...lbs. per sq. in.	80	120	60	125	95	85	125	250	150	155	100
Cut-off in 1st cylinder ....per cent	—	8.4	—	12.8	11.1	—	43.1	6.5	26.7	16.1	29.7
Speed per minute ....turns	152.4	172.3	156.1	136.3	135.2	145.9	172.9	159.9	139.9	149.0	181.8
Do. ....feet of piston	304.8	287.2	234.1	284	270.4	340.4	317	266.5	326.4	372.5	424.2
Indicator horse-power: 1st cylinder...I.H.P.	—	13.88	—	23.43	19.82	20.15	9.06	11.36	11.76	13.51	18.23
Do. 2d cylinder... „	—	—	—	—	—	—	12.05	7.27	11.01	10.504	3.87
Do. together ...... „	—	—	—	—	—	—	21.12	18.638	22.77	24.02	22.107
Break horse-power....................B.H.P.	15.31	11.37	—	16.976	16.94	17.08	17.25	17.57	20.33	21.07	18.52
Do. in parts of I.H.P., per cent	—	81.9	—	72.4	85.5	84.8	81.8	94.3	89.3	87.7	83.7
Coal consumed per hour.................lbs.	98.93	31.48	27.01	45.57	44.03	87.386	63.43	34.14	37.61	46.02	102.3
Do. do. per I.H.P...... „	—	2.27	—	1.94	2.22	4.34	3.03	1.83	1.65	1.92	4.63
Do. do. per B.H.P...... „	6.466	2.766	7.111	2.684	2.599	5.114	3.675	1.943	1.850	2.184	5.535
Water evaporated per hour.............. „	901	390	183.5	609	491	889.5	683	419	485	580	—
Do. do. per I.H.P... „	—	28.10	—	25.99	24.77	44.14	•32.34	22.48	21.30	24.15	—

Table No. 174.—"COMPARISON BETWEEN THE THEORETICAL AND ACTUAL ECONOMY DERIVED FROM AN INCREASE OF STEAM PRESSURE."

	Cardiff.	Newcastle-on-Tyne.		
	Reading Iron-works. Simple.	Davey, Paxman, & Co. Simple.	Davey, Paxman, & Co. Compound.	Edward Foden. Compound.
ORDER NUMBER.....................	—	6.	9.	8.
1. Steam pressure above atmosphere...lbs.	80	95	150	250
2. Temperature of steam .... Fahrt.	324°	334°	365°	406°
3. Corresponding absolute temperature .... "	784°	794°	825°	866°
4. Falls of temperature to 215 degrees or 675 degrees absolute... "	109°	119°	150°	191°
5. Proportions which the falls bear to the original absolute temperatures	.139	.150	.182	.220
6. The reciprocals of the above ratios, to which reciprocals the fuel actually consumed should correspond, reduced to the Reading Engine as unity	1.000	.927	.763	.682
7. Water actually consumed per break horse-power per hour (not including jacket-water) .... lbs.	30.22	26.40	21.33	21.38
8. Relative proportion of water used	1.000	.873	.706	.707

CHAPTER LIV.—SEMI-PORTABLE UNDERTYPE COMPOUND STEAM ENGINE, OF 20 NOMINAL HORSE-POWER.

DESIGNED AND CONSTRUCTED BY MESSRS. R. HORNSBY & SONS, GRANTHAM.

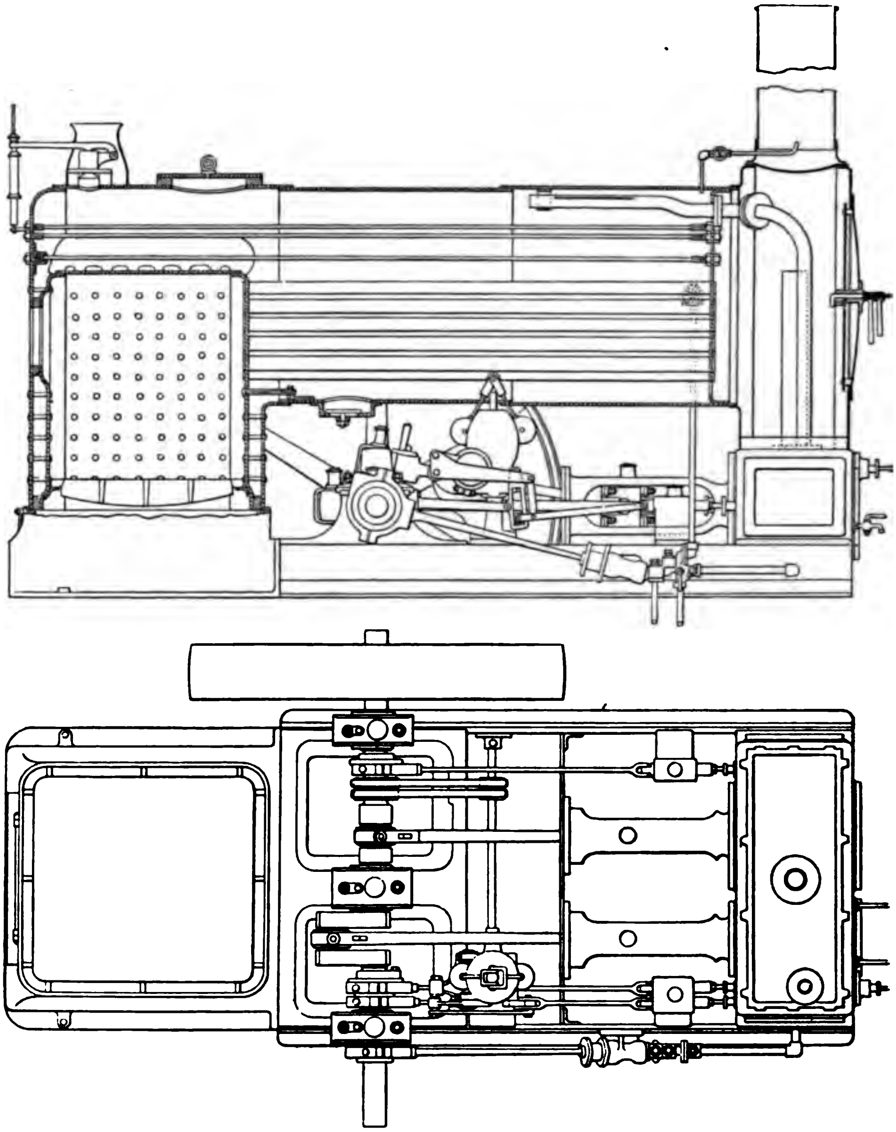
(Cylinders 8 inches and 14 inches in diameter, stroke 16 inches.)

Semi-portable steam engines are such as combine in one structure the engine and the boiler, and may be taken as portable engines without wheels. The engine may be placed on the top of the boiler, as in ordinary portable engines; or below the boiler on a special base-frame, known as the undertype system, exemplified by Messrs. Hornsby's engine, here illustrated, figs. 809 and 810.

The boiler is of the portable class, and is of steel. The fire-box is of Lowmoor iron plates, 7/16 inch thick, except the tube-plate, 5/8 inch; 37 inches long, 34¾ inches wide inside. The shell is of 3/8-inch plates, 3 feet 8½ inches long, 3½ feet wide outside. The barrel of the boiler has 3 feet 4½ inches mean diameter inside, and is 7½ feet long. There are 48 iron flue-tubes, 2½ inches in diameter externally, 7 feet 4¾ inches long between the plates, No. 12 to No. 14 wire-gauge in thickness. T are arranged in vertical rows. The chimney is cylindrical, 15 inch

diameter, 10 feet high. The working pressure is 140 lbs. per square inch.

The single-riveted seams have $2\frac{1}{2}$ inches of lap, made with $\frac{3}{4}$-inch rivets, at $1\frac{3}{8}$ inches of pitch. The longitudinal seams of the barrel are



Figs. 809.—Hornsby & Sons' Undertype Compound Engine and Boiler: Sectional Elevation and Plan. Scale 1/38th.

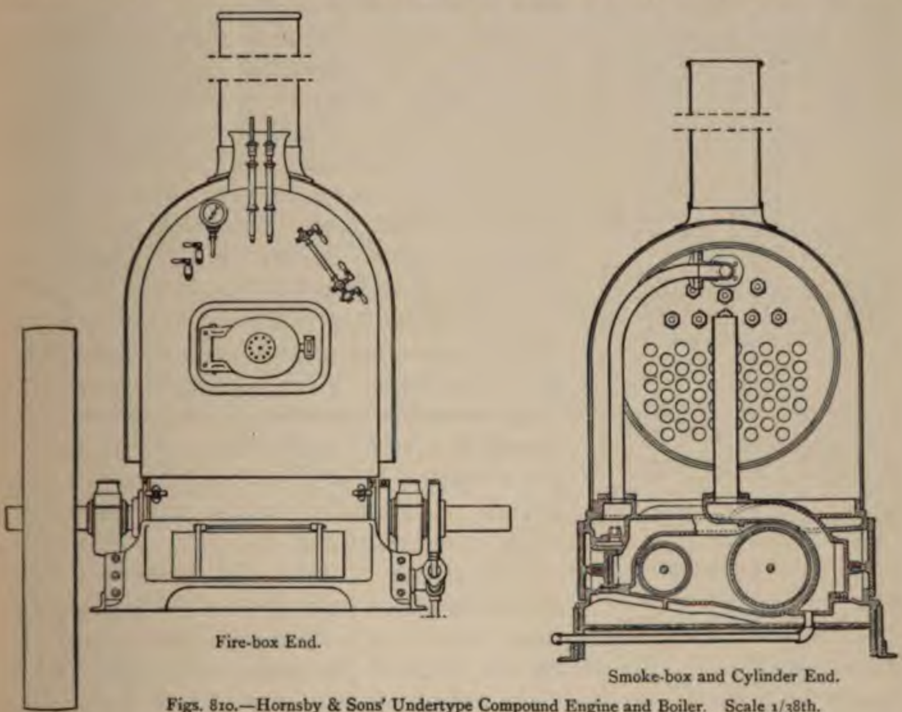
double-riveted, with 4 inches of lap, made with $\frac{3}{4}$-inch rivets, at $2\frac{1}{2}$ inches of pitch longitudinally. The factor of safety is 5.

The fire-bars are of cast iron, $^{11}/_{16}$ inch thick ... nch air-spaces.

The area of the fire-grate is 9 square fe ... rface of the

fire-box is 50.21 square feet, and of the flue-tubes 235 square feet; together, 285.21 square feet, or 31.7 times the area of grate.

The cylinders are horizontal, 19½ inches apart between their axes, compounded, 8 inches and 14 inches in diameter, with a stroke of 16 inches, connected to cranks at right angles on the main shaft. The areas of the cylinders are as 1 to 3.06. They are $^{11}/_{16}$ inch in thickness, and are inclosed in the receiver, and enveloped in receiver-steam. The valve-chests are on the outer sides of the respective cylinders. The steam is taken from the boiler by a 2¼-inch iron pipe, $^{3}/_{16}$ inch thick, slotted at the upper side to receive the steam. The blast-pipe is of cast iron, 4 inches in diameter,



Fire-box End.

Smoke-box and Cylinder End.

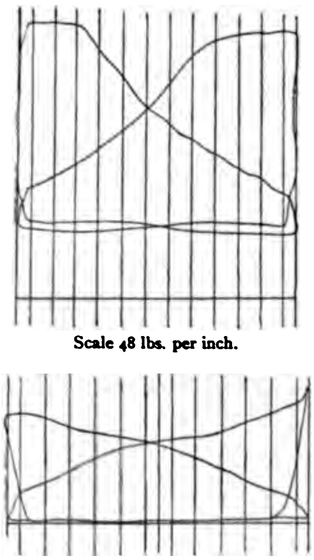
Figs. 810.—Hornsby & Sons' Undertype Compound Engine and Boiler. Scale 1/38th.

of ⅜-inch metal; and the orifice is of the same size. It terminates at a level 18 inches below the crown of the smoke-box.

The main shaft or crank-shaft is of steel, 4⅝ inches in diameter, formed with two double-cranks at right angles. The journals are 7 inches long, except the middle journal, which is 9 inches long. The crank-pins are 4⅝ inches by 3½ inches long.

The normal speed of the engine is 135 turns, or 360 feet of piston per minute. By cutting off steam at from ⅜ths to $^{7}/_{16}$ths of the stroke, or from 40 per cent to 44 per cent, it is found that the maximum of power—about three times the nominal power—is obtained with great economy of steam. The annexed sample indicator diagrams, figs. 811, show the distribution of the steam and the power. With steam of 140 lbs. pressure per square inch

and a speed of 133.5 turns per minute, the initial pressure in the first cylinder is 128 lbs. per square inch above the atmosphere; and the back pressure is 28 lbs. above the atmosphere. In the second cylinder the mean initial pressure is 28 lbs., and the back exhaust-pressure is ¾ lb. per square inch above the atmosphere. The average effective pressure in the first cylinder is 62.4 lbs., and in the second 17.12 lbs. per square inch. For the speed of piston, 356.65 feet per minute, the horse-power developed in the first and second cylinders respectively are 33.8 and 28.4 horse-power; or, together, 62.2 indicator horse-power. The steam is cut off in the first cylinder at a mean of about 31 per cent; and the nominal ratio of expansion is about 9 times.



Scale 48 lbs. per inch.

Scale 24 lbs. per inch.

Figs. 811.—Hornsby's Undertype Compound Engine: Indicator Diagrams.

The average results of three trials, lasting each 6 hours 20 minutes, made with a 20-horse-power engine whilst on ordinary work, are as follows:—Speed, 134.06 turns, or 357.50 feet of piston per minute. Indicator horse-power, first cylinder, 33.82; second cylinder, 31.16; both cylinders, 64.98. Smokeless Welsh coal consumed 967.6 pounds, or 153 pounds per hour, or 17 pounds per square foot of fire-grate, or 2.35 pounds per indicator horse-power. Water evaporated 9260 pounds, or 148.4 cubic feet, supplied at 50° F.; or 1463 pounds, or 23.44 cubic feet per hour; or 2.80 cubic feet per square foot of fire-grate area; or 22.5 pounds per indicator horse-power per hour; or 9.57 pounds per pound of coal, or 12.15 pounds of water from and at 212° F.

The engine is fitted with Hornsby's automatic expansion valve-gear, which has already been noticed in a different form, at page 35. An expansion-valve works on the back of the main slide-valve, and is moved by a special eccentric, the rod of which is pinned to a slotted link suspended from a fixed pin or stud above it. By the shifting vertically of a slide-block in the slot, by the action of the governor in the manner already explained, the travel of the valve, which is connected by a radius-link to the sliding block, is varied, and in consequence also the period of admission.

The weight of the engine complete is 9 tons 7 cwts. The price is £480, or £51, 7*s.* per ton.

The rule for calculation of nominal horse-power, of such compound engines, practised by Messrs. Hornsby, is as follows:—Multiply the square of the diameter of the first cylinder in inches by 2, and divide the product by 8. The quotient is the nominal horse-power. The form of this rule is a recognition of the second cylinder. But the same result is obtained by dividing the square of the diameter by 4.

Undertype Steam Engines: Messrs. R. Hornsby & Sons.

Working Pressure 140 lbs. per square inch.

Horse-power.	Grate-area.		Heating Surface.					Approximate Weight.	Price.	
	Area.	Per H.P.	Fire-box.	Tubes.	Total.	Per H.P.	Per Square Foot of Grate.		Amount.	Per Ton.
H.P.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	tons. cwt.	£	£ s.
8	4.30	.53	26.20	81.12	107.34	13.41	31.2	4 12	280	60 18
10	5.20	.52	31.12	117.28	153.01	15.30	29.4	5 7	310	58 0
16	7.36	.47	45.71	176.40	222.10	13.80	30.2	8 0	410	51 5
20	9.04	.45	50.21	235.00	285.21	14.20	30.4	9 7	480	51 7
25	10.39	.41	55.63	272.27	327.90	13.10	31.5	10 16	590	54 12
30	12.75	.42	63.00	322.50	385.50	12.85	30.2	13 0	690	53 1
40	16.10	.40	80.00	430.90	510.00	12.75	31.6	18 0	980	54 9
50	19.5	.39	80.00	544.17	624.17	12.48	32.0	21 0	1110	52 17

Horse-power.	Diameter of Cylinders.		Stroke.	Speed per Minute.		Fly-wheel.		Indicator H.P.		Break H.P.	
	First.	Second.		Turns.	Feet of Piston.	Diameter.	Width.	Maximum.	With Economy.	With Economy.	In Parts of Indicator H.P.
H.P.	inches.	inches.	inches.	turns.	feet.	feet.	inches.	I.H.P.	I.H.P.	B.H.P.	per cent.
6	4½	8	10	220	367	4	5	20	18	15	83.3
8	5	9	12	180	360	4½	6½	26	24	20	83.3
10	6	10½	14	155	362	5	8	33	30	25	83.3
12	6½	11¼	14	155	362	5	8½	39	36	30	83.3
16	7¼	12¾	16	135	360	6	9	52	48	40	83.3
20	8	14	16	135	360	6	10½	65	60	50	83.3
25	9⅛	16	18	120	360	7	12	80	75	62	82.7
30	10	17½	18	120	360	7	14	96	90	75	83.3
40	12	21	24	90	360	one 8 or	20 or 12	128	120	100	83.3
50	13	23	24	90	360	two 7	25 or 15	160	150	125	83.3

MULTIPLE-COMPOUND OR MULTIPLE-EXPANSION STATIONARY STEAM ENGINES.

CHAPTER LV.—INTRODUCTION.

By a simple process of induction, it is readily inferred that as compound steam engines have proved more economical than single-cylinder engines, so it is open for multiple-expansion, in more than two cylinders, to excel compound engines in efficiency and economy. As in the single cylinder, the range of internal temperature and the consequent condensation and re-evaporation of steam is greater than when apportioned between two cylinders compounded; so in the compound engine of two cylinders, the individual range is greater than in multiple-expansion in three or more cylinders.

Such is the common argument in favour of multiple-expansion. But it is scarcely sufficient, seeing that, though in individual cylinders compounded the range of temperature is less than in a simple cylinder, yet the total range between the initial temperature in the first cylinder and the final temperature in the last cylinder is practically equal to the range in a simple cylinder for equal ranges of expansion and pressure; and the total loss of efficiency due to condensation and re-evaporation should be the same in amount.

The specific reason for the augmented efficiency procured by multiple-expansion is due to the fact that, as shown by the diagram and table in pages 473 and 474, vol. i., the proportion of steam condensed is comparatively very small for periods of admission of half the stroke or of longer periods; whilst for periods less than half-stroke the proportion increases very rapidly—in an accelerated ratio—as the cut-off is reduced; insomuch that, in cutting off at 10 per cent of the stroke there is, in addition to the sensible steam cut off, steam condensed to the extent of 80 per cent of this sensible steam; otherwise, of the whole steam admitted, 44 per cent is condensed. In cutting off at or about half-stroke, therefore, in multiple-expansion engines, a great degree of expansion is attainable, without the injurious condensation and re-evaporation incident to shorter admissions; and, for this reason, economical results have been obtained from compound or multiple-cylinder engines without the employment of steam-jackets; or where the first cylinder only has been steam-jacketed.

Mr. Daniel Adamson, in advance of his time, described, in 1875, a four-cylinder or quadruple-expansion condensing steam engine, horizontal; whereof the first and second cylinders, in tandem, were connected to one end of the main shaft, and the third and fourth cylinders, in tandem, were connected to the other end. The cranks were at right angles, and an intermediate steam-jacketed receiv per system, was placed

between the two lines of cylinders, in connection with the second and third cylinders. The working pressure in the boilers was 110 lbs. per square inch. The cylinders were respectively 17 inches, 22½ inches, 30¼ inches, and 42 inches in diameter, with a stroke of 5 feet. The capacity-ratios of the cylinders were as 1, 1.75, 3.17, and 6.10. The indicator horse-power is said, in one trial, to have been 540; 1.77 pounds of coal having been consumed per horse-power per hour.

CHAPTER LVI.

HORIZONTAL TRIPLE-COMPOUND CONDENSING STEAM ENGINE, FOR 1200 INDICATOR HORSE-POWER.

CONSTRUCTED BY MESSRS. TIMOTHY BATES & CO. (POLLIT AND WIGZELL), SOWERBY BRIDGE.

(Cylinders 16 inches, 26 inches, and 46 inches in diameter; stroke 5½ feet.)

This engine, figs. 812 and 813, was constructed for Messrs. John Dickinson & Co., Croxley Paper Mills, Watford. It has three horizontal cylinders, respectively 16 inches, 26 inches, and 46 inches in diameter, all with a stroke of 5½ feet, in the capacity-ratios of 1, 2.64, and 8.26. The cylinders are placed upon two separate cast-iron bed-frames: the first cylinder on one bed-frame, the second and third cylinders on the other bed-frame. They are connected to cranks on the ends of the main shaft, on the middle of which the fly-wheel is carried. By this arrangement two distinct engines are provided; and, in case of accident to the first engine, or to the steam boilers whereby the supply of steam is curtailed, the first engine may be uncoupled, and the second engine, comprising the second and third cylinders, can be set to drive a large proportion of the work with a reduced boiler pressure, precisely in the manner of the compound engine by the same constructors already described and illustrated, page 267. At normal speed the engine makes 75 revolutions, or 825 feet of piston, per minute. The working pressure in the boilers is 150 lbs. per square inch.

The bed-frames are each a box-casting, of uniform width, 5¼ feet at the upper part, 5 feet 11 inches over the base flanges. Each is cast in three pieces, of which the first piece, carrying the main bearing, extends to the back of the slides, and is 23 inches high. The second piece extends to the back of the second cylinder, and the third to the condenser. The average thickness of metal is 1¼ inches; it is 1½ inches thick at the main bearing.

The section of the frame is shown in fig. 815.

The first cylinder, figs. 814 and 815, is of 1¼-inch metal, and is steam-jacketed, at the sides. The jacket is also of 1¼-inch metal; it is of the same length as the cylinder, and the cylinder-covers are bolted to it, with 1½-inch flanges 1½ inches thick at the back, and 1⅝ inches at the front or stuffing-box end. The length inside between the covers is 6 f

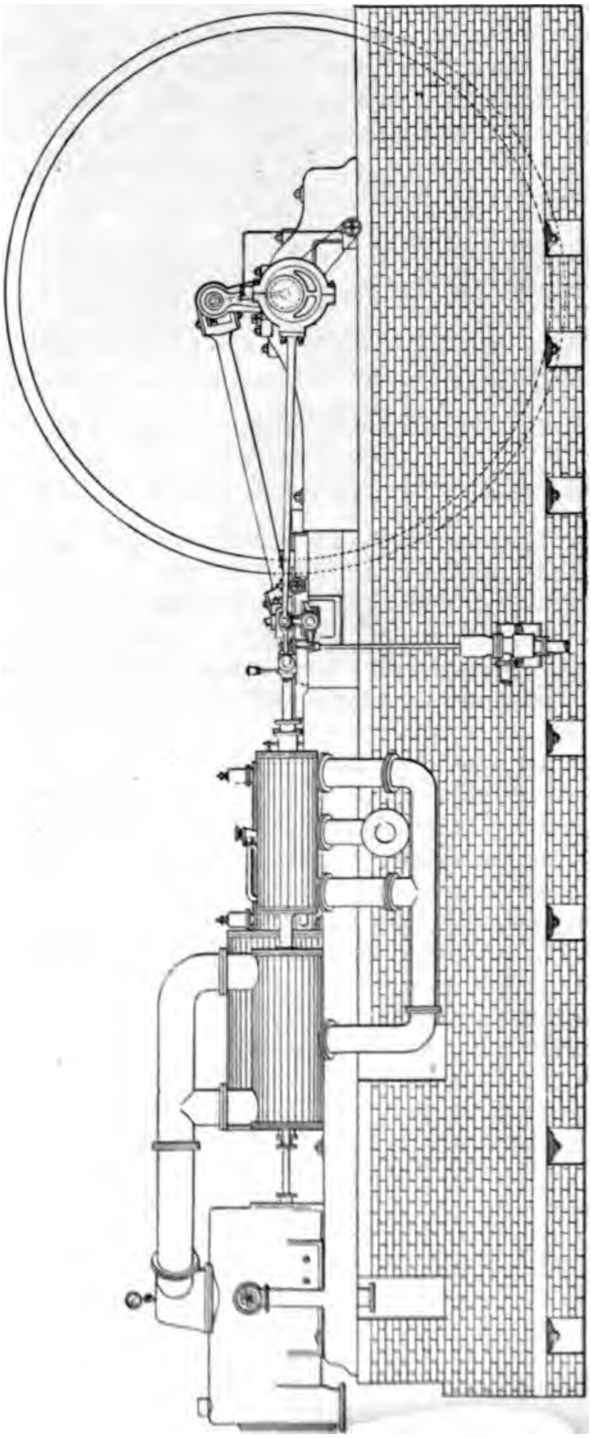


Fig. 812.—T. Bates & Co.: Triple-compound Condensing Steam Engine. Elevation. Scale 1/80th.

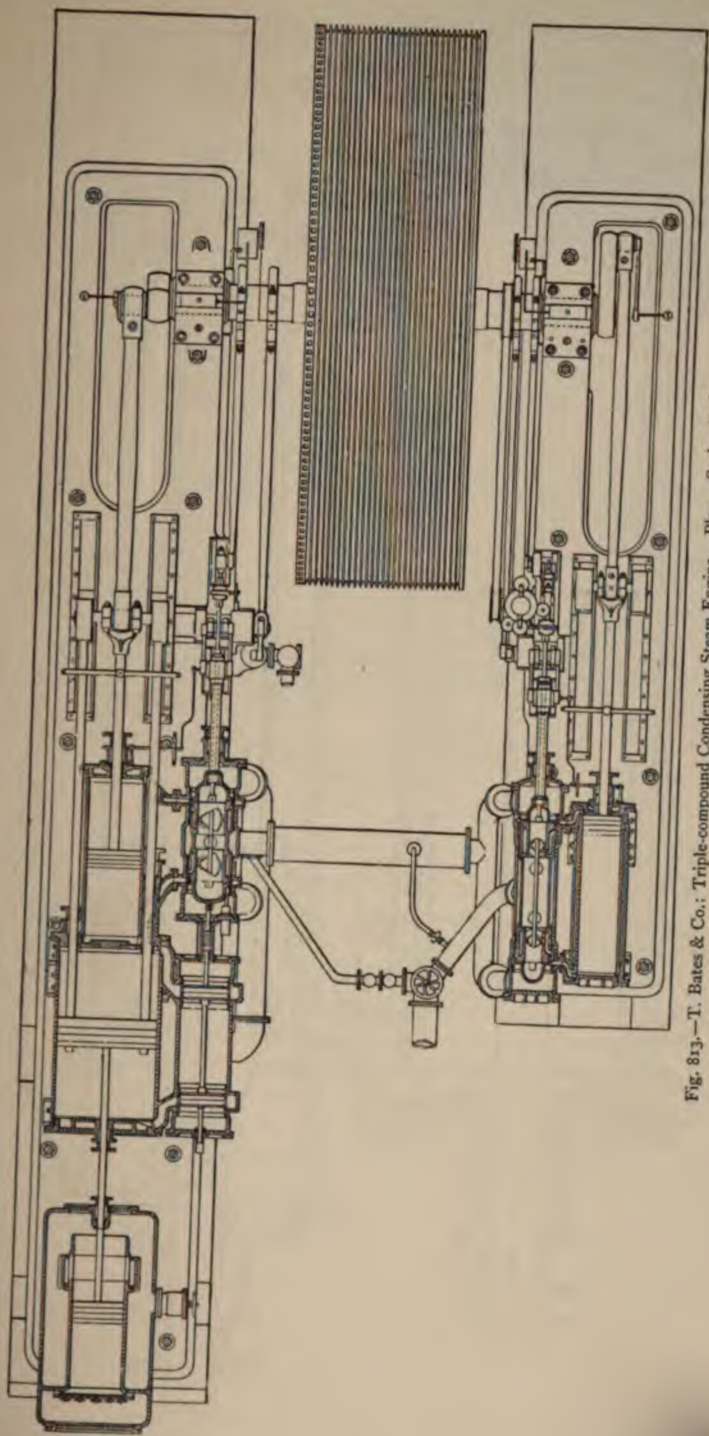
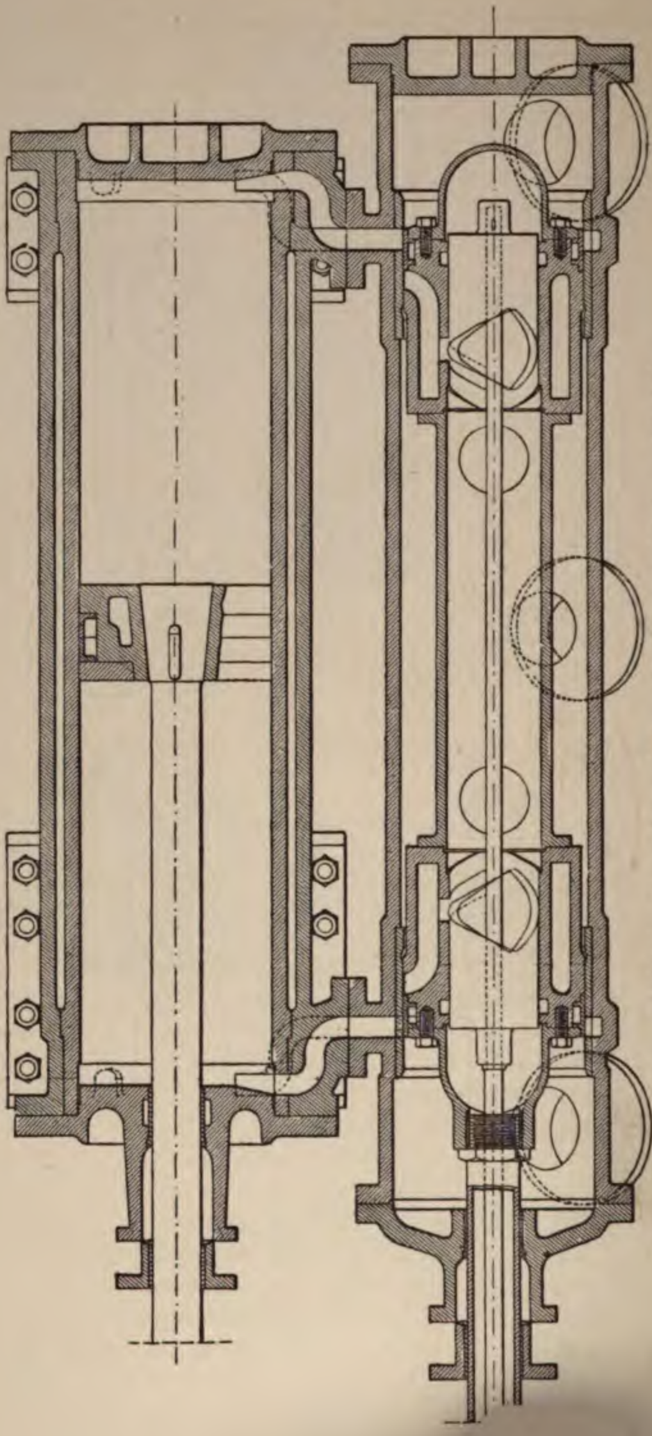


Fig. 813.—T. Bates & Co.: Triple-compound Condensing Steam Engine. Plan. Scale 1/80th.



Figs. 814.—Bates' Engine: First Cylinder and Piston-valve. Longitudinal Sections. Scale 1/16th.

3½ inches, allowing 8 inches for the thickness of the piston, and ¾ inch clear space at each end of the stroke. The cylinder is bolted down to the base with eight 1½-inch bolts and nuts, four at each side. The main steam-pipe is 7 inches in diameter, and is of ¾-inch metal.

The first cylinder is fitted with a piston-valve, shown in figs. 814 and 815, patented by Messrs. Pollit & Wigzell—a long hollow piston having metal rings and spring packing at each end to regulate the admission and the exhaust of the steam at each port. The casing or valve-chest is of

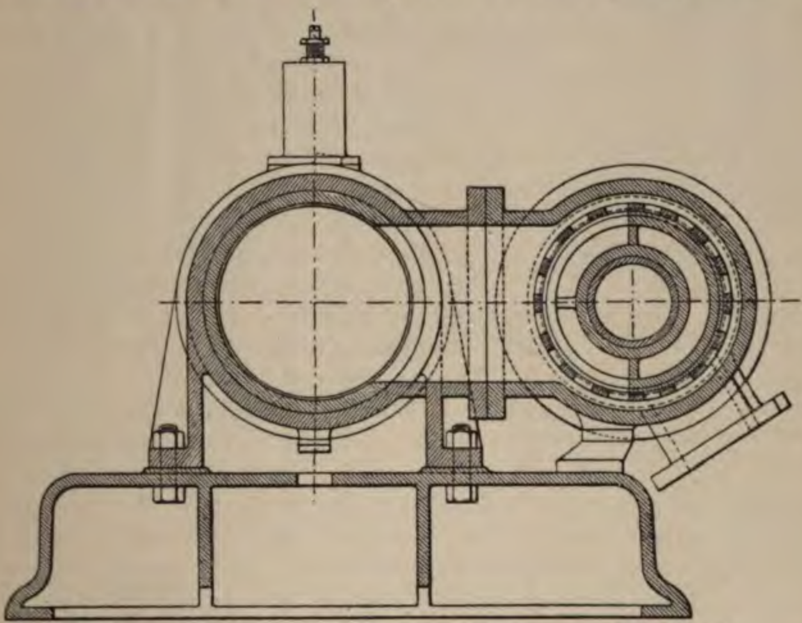


Fig. 815.—Bates' Engine: First Cylinder and Piston-valve. Cross Section. Scale 1/16th.

1⅛-inch metal, 15½ inches in diameter inside, enlarged to 17 inches at each end. Steam is brought to the chest by a 6-inch steam-pipe, from which it is delivered around the middle or body of the piston, which is 7¾ inches in diameter inside, and into the interior of it through openings. Thence it is admitted into the cylinder at each end, through ports in the main cylindrical valve, which is 7½ inches in diameter inside, controlled by an automatic cut-off or expansion-valve, accurately fitting and working within the main valve. The ports in the main valve are cut diagonally, as developed in fig. 816, and the edges of the cut-off valve are sloped to the same angle. By the action of the governor a revolving or twisting movement is communicated to the cut-off valve-rod, by which the valve is moved slightly round one way or the other; thus automatically increasing or reducing the lap, and correspondingly reducing or increasing the period of admission of steam to the cylinder.

The main valve is worked by one eccentric, and the cut-off valve by a separate eccentric, with a stroke of 6½ inches for each valve. Th

valve-rod is a steel tube, 4 inches in diameter outside, working through a stuffing-box. The cut-off valve-rod is of mild steel, 1½ inches in diameter, reduced to 1¼ inches inside the valve-chest. It works within the tubular rod of the main valve. The exhaust steam passes from each end of the valve-chest through a 7-inch branch exhaust-pipe, the two branches being united to one pipe of the same diameter, which conducts the steam to the second cylinder. Thus, the maximum pressure of steam is limited to the space between the piston packings; whilst the tube and the joints of the valve-box covers are subjected only to the exhaust pressures from the cylinder.

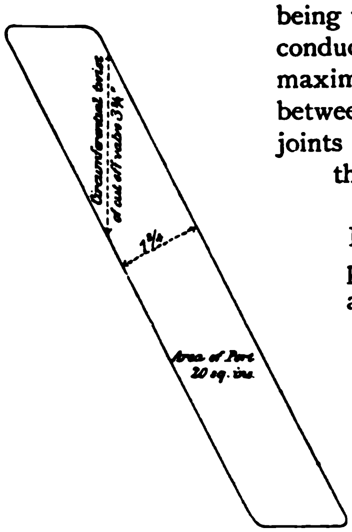


Fig. 816.—Bates' Engine: Obliquity of Steam-port of Main Valve. Scale ⅛th.

The second cylinder is of 1⅛-inch metal. It is fitted, like the first cylinder, with the patent piston-valve, having 6½ inches of stroke, and is worked in the same way, except that the period of admission is regulated by hand, by means of a worm and worm-wheel. By this means—altering the cut-off in the second cylinder—any required back pressure can be turned on the first piston while the engine is at work.

The third cylinder is of 1¼-inch metal. It is fitted with two ordinary piston-valves with metal rings and spring packings, cottered upon one rod, which is cottered to and worked by the main piston-valve of the second cylinder. The two valve-box covers are connected by a tube, through which the valve-rod works; a long metal piston, fixed on the rod, works within the tube, making a steam-tight separation between the second and third valve-chests, and so dispensing with two stuffing-boxes which would otherwise have been necessary. Thus, altogether only two stuffing-boxes are required for the piston-valves; and these are at the front ends of the valve-chests, in full view of the attendant, and easily accessible.

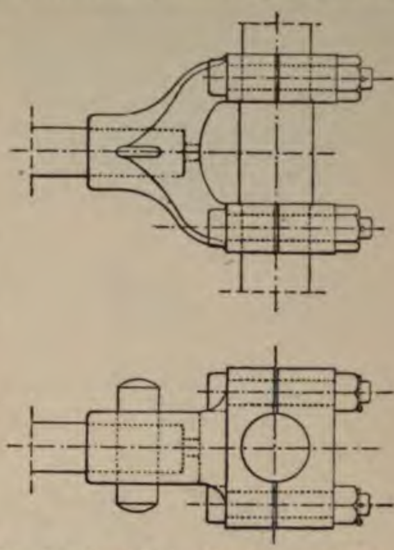
The valve-boxes are each fitted with a liner over the steam-ports, with diagonal openings, which can be readily renewed in case of wear.

The intermediate 7-inch exhaust-pipe, between the first and second cylinders, is treated as a receiver, and is encased by a cast-iron jacket, 7 feet in length, 12 inches in diameter inside, supplied with steam direct from the main steam-pipe. Through a reducing valve connected to the main steam-pipe, steam can be turned on for blowing through, or for warming the second and third cylinders. The first and second cylinders are fitted with a large spring safety-valve at each end.

The areas for steam admission through the valves, and the port areas, are as follows:—

	Steam Admission.	Port Area.
First main valve..................	16 square inches.	24 square inches.
Second do.	32 „ „	50 „ „
Third cylinder..		„

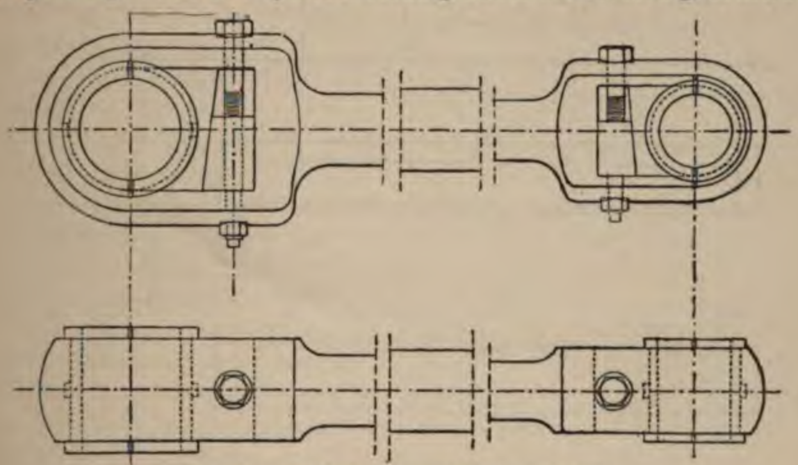
The design and arrangement of the second and third cylinders in combination have already been noticed in describing the compound steam engine, Plate X., page 267: an exact counterpart, except in the employment of piston-valves in place of slides.



Figs. 817.—Bates' Engine: Crosshead. Scale 1/8th.

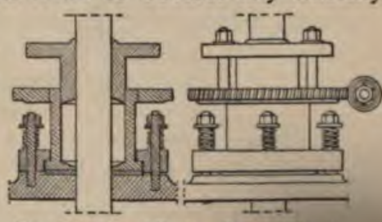
The piston-rods are of Siemens-Martin mild steel, 4¼ inches in diameter. The journals of the crank-pins are 4½ inches by 6 inches long; those of the crosshead-pins, figs. 817, are 4 inches by 5¼ inches long; both of mild steel. The connecting-rod, figs. 818, is 13 feet 9¾ inches in length, or five times the length of the cranks. It is round, and is 5 inches, 7 inches, and 6 inches in diameter at the crosshead end, the middle, and the crank end, respectively.

The stuffing-boxes are filled with metal packing. The two cylinder stuffing-boxes are revolving, constructed



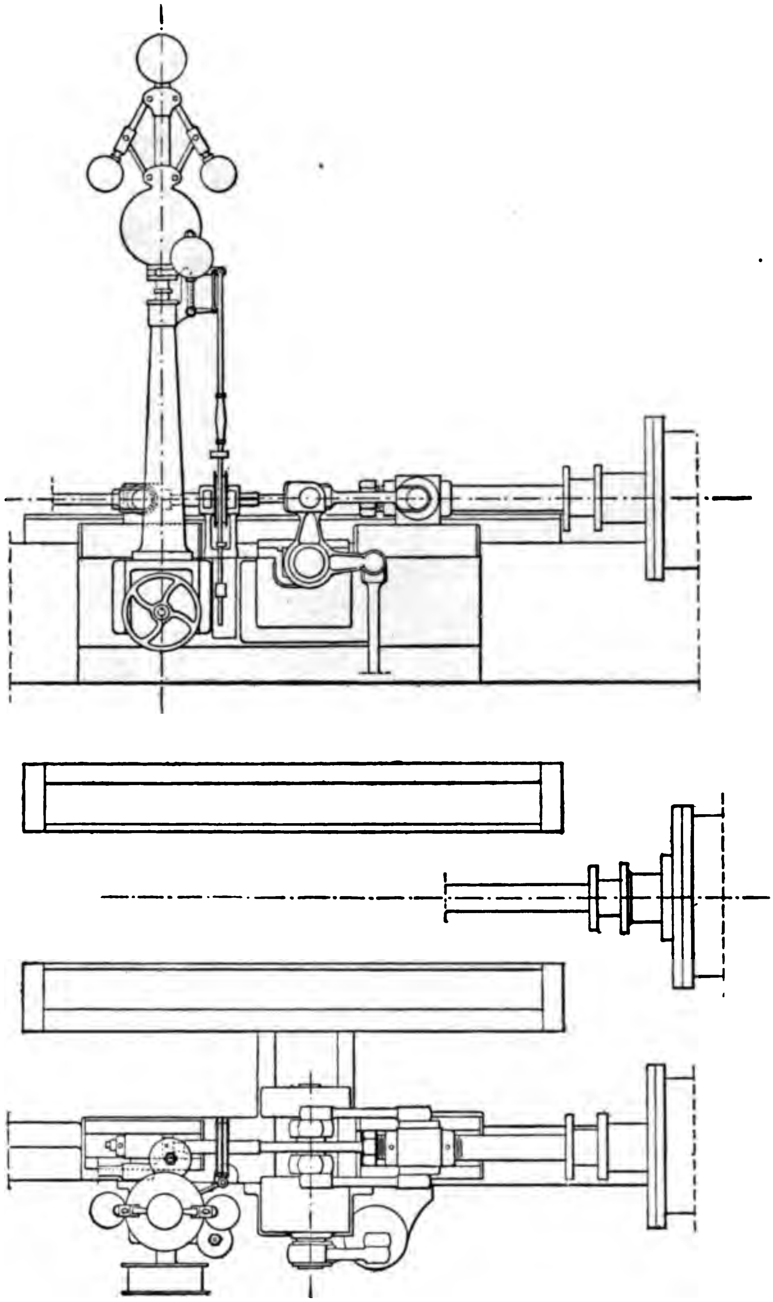
Figs. 818.—Bates' Engine: Connecting-rod. Scale 1/8th.

on Sparkes' system, shown in figs. 819, in order to obviate any liability to scoring of the piston-rods, or inequality of wear, and to reduce friction and wear of packing. The stuffing-box is formed separately from the cylinder-cover, to which it is attached by means of stud-bolts and a keep-ring, held to the cylinder-cover by a helical spring on each bolt, in compression. Thus the stuffing-box, whilst it is



Figs. 819.—Bates' Engine: Sparkes' Revol- Stuffing-box.

held firmly, is free to revolve; and for the purpose of circular movement, it



Figs. 820.—Bates' Engine: Isochronous Governor. Scale 1/32d.

is fitted with a worm-wheel, geared with a worm which is slowly turned by a ratchet-motion from the valve-rod or other convenient reciprocating member.

The condenser is on the principle already described in page 268. It is of ⅞-inch metal. The air-pump is 23 inches in diameter, 1 inch thick.

The governor is on the principle of the Collamore governor attachment already described, page 82; with the difference in detail that, instead of the toothed sector and rack there described, a smooth pulley and bow-string connection with the governor is employed for moving the tumbling weight. The apparatus is shown in figs. 820 and 821, where it is seen that the bow-string attached by the ends to the governor slide is passed once round the pulley, which moves one way or the other on its axis, and turns the cut-off valve-rod, as already described. The speed of the engine and the governor is constant, though the plane of rotation of the governor-balls varies.

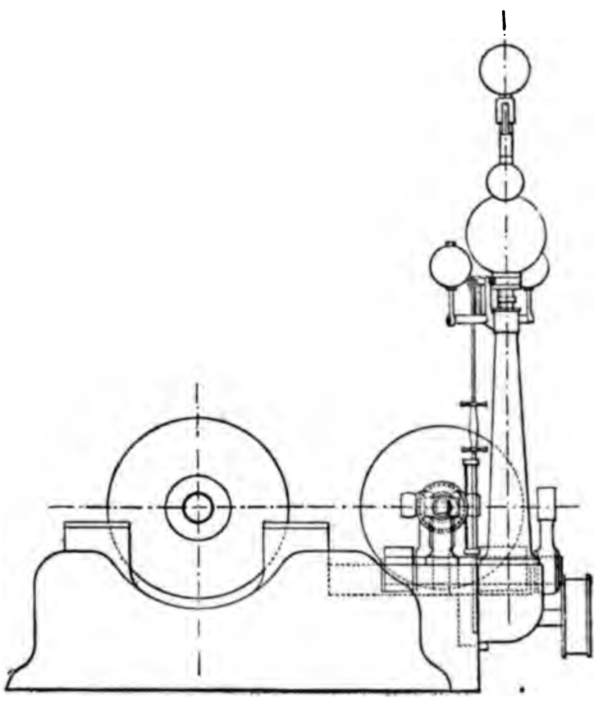
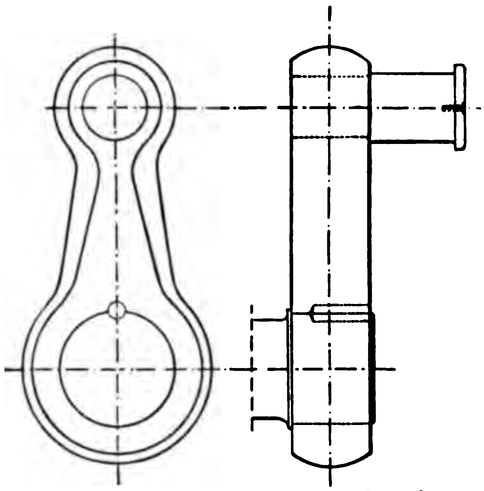


Fig. 821.—Bates' Engine: Isochronous Governor. Side View. Scale 1/32d.

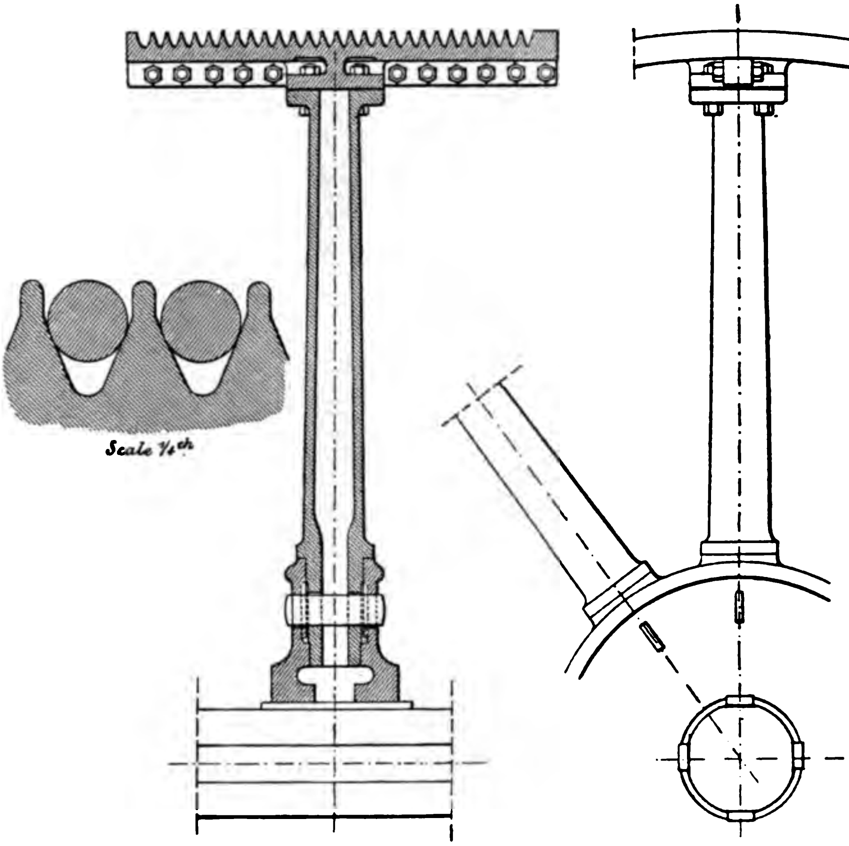
The fly-wheel shaft is of mild steel, having two journals, 12½ inches in diameter, 26 inches long, enlarged to 18 inches in diameter at the middle for carrying the fly-wheel. One of the cranks is shown in figs. 822; the large eye is 14 inches in diameter to fit the shaft; the smaller eye is 7⅝ inches for the crank-pin, which is 8½ inches in diameter, 10⅞ inches long for the journal. A loose collar is fitted to the end of the journal, and is fastened with recessed screws.



Figs. 822.—Bates' Engine: Crank. Scale 1/24th.

The crank is secured on the shaft with a 2-inch round pin let half into the crank and h[illegible] shaft. The crank is 10 inches thick, 23½ inches in diameter [illegible] inches over the pin.

The fly-wheel, figs. 823, is of cast iron, 20 feet in diameter. The rim of the wheel is 6 feet wide, turned to receive 28 ropes 1⅝ inches in diameter, to the section shown in detail, with holes for barring. The ropes are of



Figs. 823.—Bates' Engine: Fly-wheel. Scale 1/32d.

cotton. When the full load is on, the working stress is 292 lbs. on each rope. The limit of working load is 350 lbs. on each rope of 1⅝ inches in diameter. The breaking stress of a 1⅝-inch rope is from 3000 lbs. to 6000 lbs. according to the quality. Worked at a lineal speed from 3000 feet to 5300 feet per minute, such ropes have a life of from 5 to 10 years.

The centre of the fly-wheel is 5 feet 5 inches in diameter, 21 inches wide in the shaft. It is fixed on the shaft with four flat mild steel keys, 4½ inches by 1½ inches. There are 10 arms, hollow, of 1½-inch metal, taper from 10 inches in diameter at the centre to 8 inches at the rim; fastened into sockets formed on the centre, with a steel cotter to each, 5 inches by 1¼ inches; bolted to the rim, which is in 10 segments, with four 1¾-inch iron bolts and nuts. The rim weighs 25 tons.

Each of the main bearings is fitted with a small oil tank and pump, shown in fig. 824, driven by a band from the ... by which a continuous flow of oil on the journals is provid... ...ing kept

in circulation. Thus the lubrication is both better done and more economical than ordinary lubrication. The bearings are kept cool and in good condition. The crank-pins are fitted with a pendulum lubricator, by which the oil is carried down the centre of the pin through small passages drilled from the outside. By these means the engine can be run continuously lubricated without requiring to be stopped to have the lubricators replenished. The lubricant being forced through the pin is regularly distributed over the whole surface.

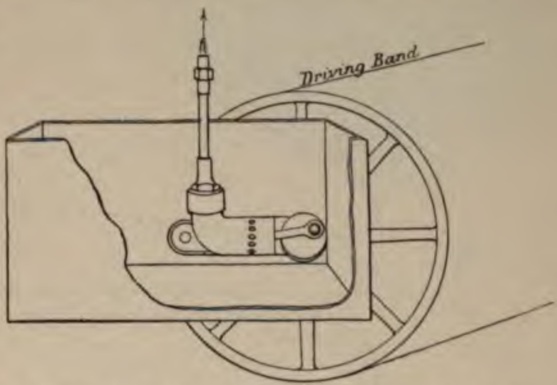


Fig. 824.—Bates' Engine: Lubrication Oil Tank for Main Bearings.

Two sets of indicator diagrams, taken in January and February, 1890, are here reproduced on a smaller scale, figs. 825 and 826. The engine made 75 revolutions per minute, in both cases. In the first case, the pressure in the boiler was 150 lbs. per square inch above the atmosphere; and the initial pressure in the first cylinder was 146 lbs., or only 4 lbs. below the pressure in the boiler.

	1st Cylinder.	2d Cylinder.	3d Cylinder.	Total.
Indicator horse-power, first set.......	380	270	230	880 H.P.
Do. do. second set...	329	356	278	963 „

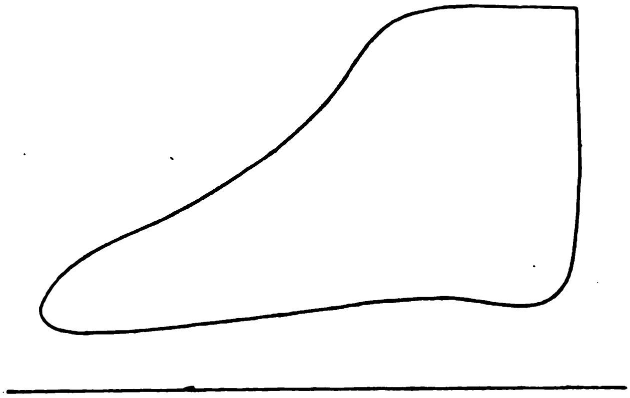
When the full load, for 1200 indicator horse-power, is applied, the additional power will be developed in the second and third cylinders. The period of admission in the first cylinder will be augmented, and a higher back pressure on the first piston may be imposed; so causing a higher admission pressure on the second piston. It is estimated that the water consumed as steam is at the rate of 13 pounds per indicator horse-power.

This engine is reported (February, 1890) to have been steadily working 140 hours per week for nearly two years, without needing any repair. On examination, all the working parts, particularly the piston-valves, were found in good order.

The limit of tensile stress in the structure of the engine is, for cast iron, 1100 lbs. per square inch; for wrought iron 4000 lbs.; and for steel (bolts and piston-rods) 6000 lbs.

The foundations, figs. 812 and 813, are 7¼ feet deep, of brick in cement, with a top and a bottom course of stone. The foundation for the first cylinder and its connections is 36½ feet long, 6 feet 1 inch wide; that for the second and third cylinders is 53 feet long, 7 feet wide.

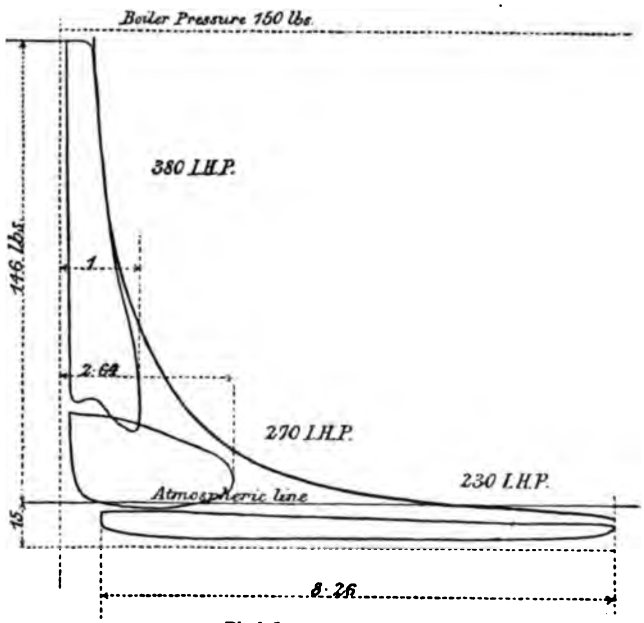
The total weight of the engine is 110 tons. The cost (1890) would be £5000, or £45, 9*s*. per ton. The cost of erection averages £2 per ton.



First Cylinder. Vertical Scale of Pressure, 72 lbs. per inch.

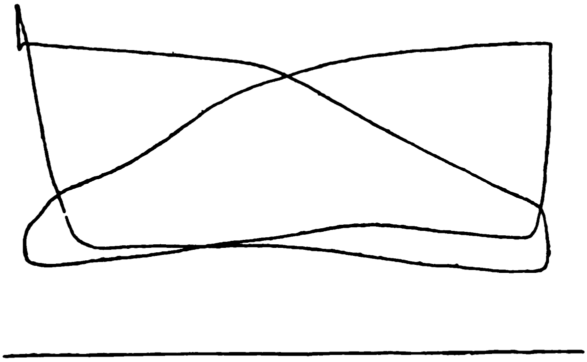
Second Cylinder. Vertical Scale of Pressure, 30 lbs. per inch.

Third Cylinder. Vertical Scale of Pressure, 18 lbs. per inch.

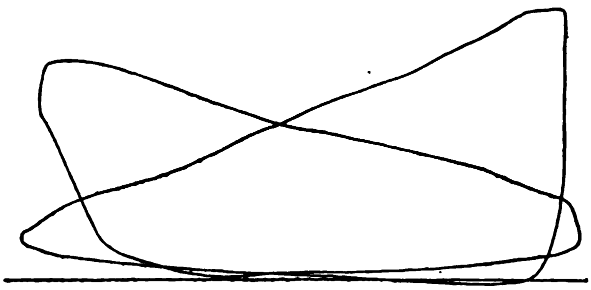


Block In'

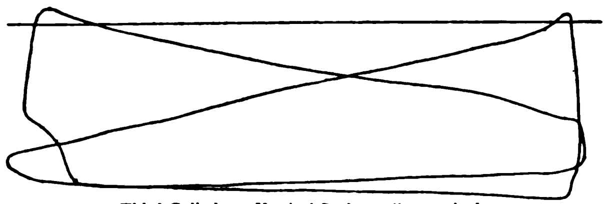
Figs. 825.—Bates' Engin First Set.



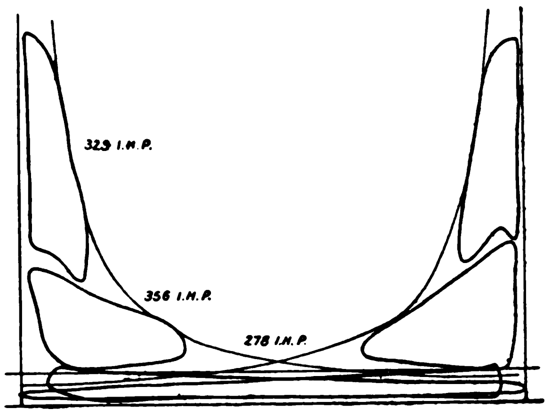
First Cylinder. Vertical Scale, 84 lbs. per inch.



Second Cylinder. Vertical Scale, 36 lbs. per inch.



Third Cylinder. Vertical Scale, 12 lbs. per inch.



Block Diagram. Vertical Scale, 80 lbs. per inch.

Figs. 826.—Bates' Engine: Indicator Diagrams. Second Set.

CHAP. LVII.—VERTICAL TRIPLE-COMPOUND CONDENSING STEAM ENGINE, FOR 600 INDICATOR HORSE-POWER.

CONSTRUCTED BY MESSRS. TIMOTHY BATES & CO. (POLLIT & WIGZELL), SOWERBY BRIDGE.

(Cylinders 16 inches, 21 inches, and 38 inches in diameter; stroke 3½ feet.)

This engine, figs. 827, 828, and 829, was constructed for the Baladina Mill, Bombay. Three overhead vertical cylinders are connected by three connecting-rods to two cranks on the main shaft below, and the power is taken off by a rope fly-wheel. The condenser and air-pump are below the floor-level. The first and second cylinders are slightly inclined to the vertical, and to each other; they are fastened to one pair of frame standards, and are connected to one crank. The third cylinder is connected to its own crank.

The cylinders are 16 inches, 21 inches, and 38 inches in diameter, with a stroke of 3½ feet; in the capacity-ratios of 1, 1.72, 5.64. The working pressure in the boiler is 150 lbs. per square inch. The engine makes 86 revolutions, or 602 feet of piston per minute. The first cylinder is steam-jacketed, and is fitted with the Pollit & Wigzell piston-valve, with an internal automatic cut-off piston-valve, controlled by the isochronous governor, the same as already described, page 457. The second cylinder is fitted with a flat slide-valve and a cut-off piston-valve working on the back of the slide-valve; regulated by hand as before explained. The third cylinder is fitted with an ordinary D slide-valve. Each valve is worked by a separate eccentric, so that each valve can be separately adjusted and set. The valve of the third cylinder has 9 inches of travel; the other valves have 6½ inches of travel. The first cylinder is of 1-inch metal; the jacket is 1⅛ inches thick, and incloses a 1-inch steam-space. The second and third cylinders are 1⅛ inches thick.

	Cylinder Ports.	Steam-admission Ports through the Valve.
1st cylinder,	10 in. × 1½ in. = 15 sq. inches.	13 sq. inches.
2d cylinder,	15 „ × 2 „ = 30 „	25 „
3d cylinder,	20 „ × 4 „ = 80 „	— —

Steam from the boiler is admitted from the main steam-pipe, of 9 inches bore, and ¾-inch metal. The stop-valve has a 6-inch bore. The steam enters at the middle of the first piston-valve, and is exhausted from it at the ends by connecting pipes into the second valve-chest. From the second cylinder it is exhausted through a single pipe to the third cylinder, and thence to the condenser. The cylinders are each fitted with spring escape-valves; and with drain-tubes and cocks at the lowest points of the cylinders and valve-chests, all connected and worked by means of one lever from the floor.

The pistons are constructed on the system ~ Pollit & Wigzell's steel coil. The piston-ro

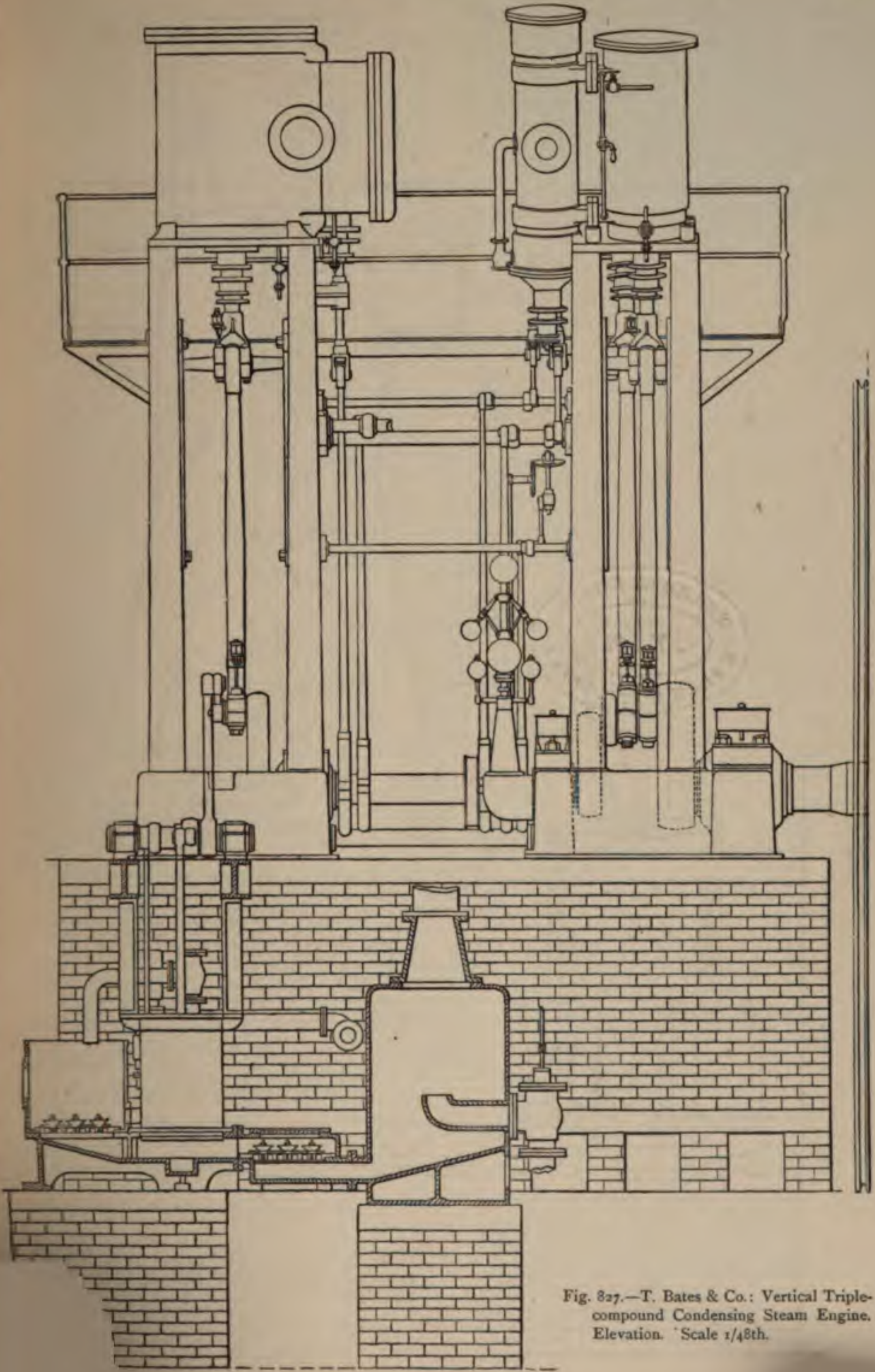


Fig. 827.—T. Bates & Co.: Vertical Triple-compound Condensing Steam Engine. Elevation. Scale 1/48th.

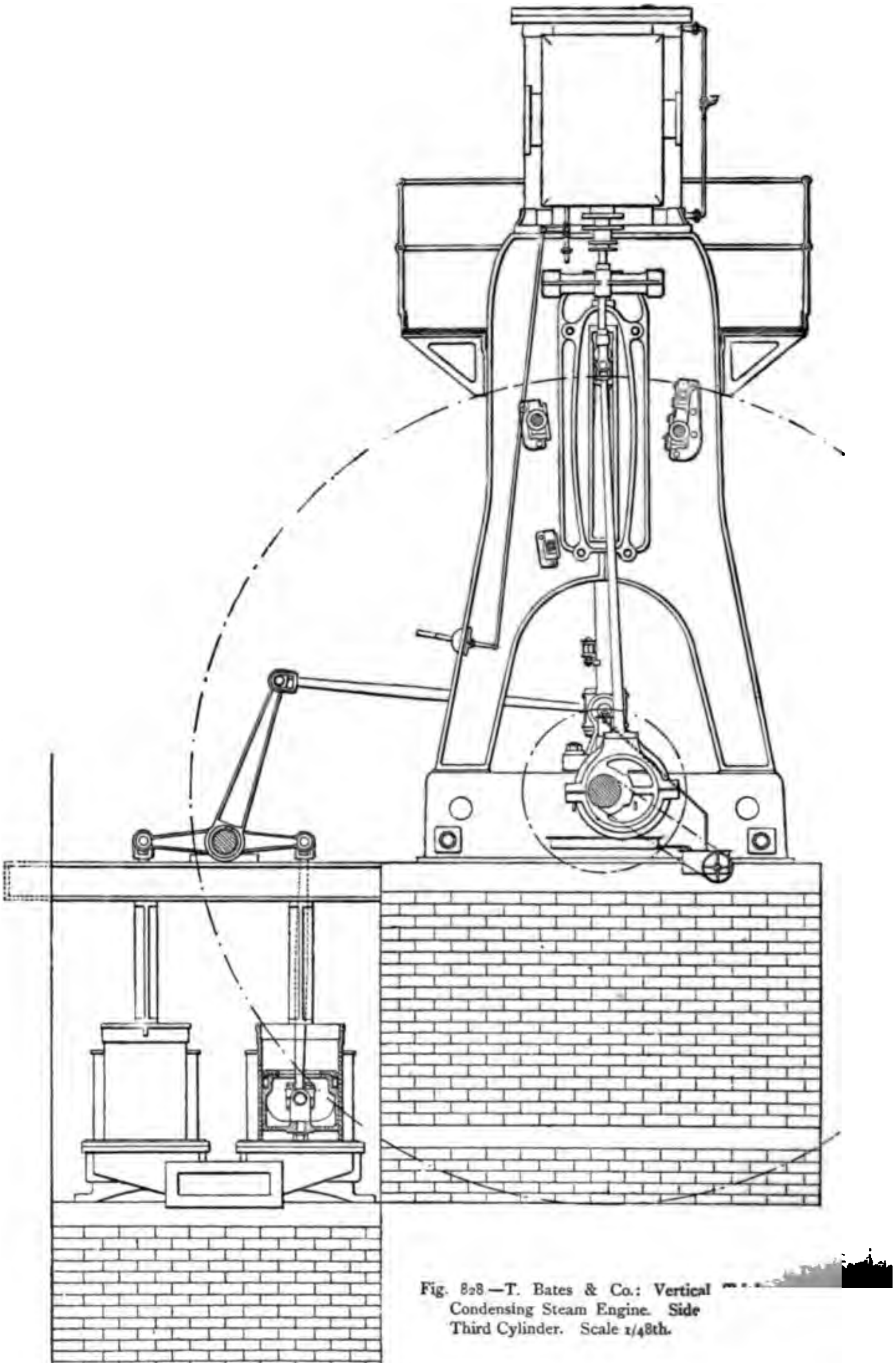
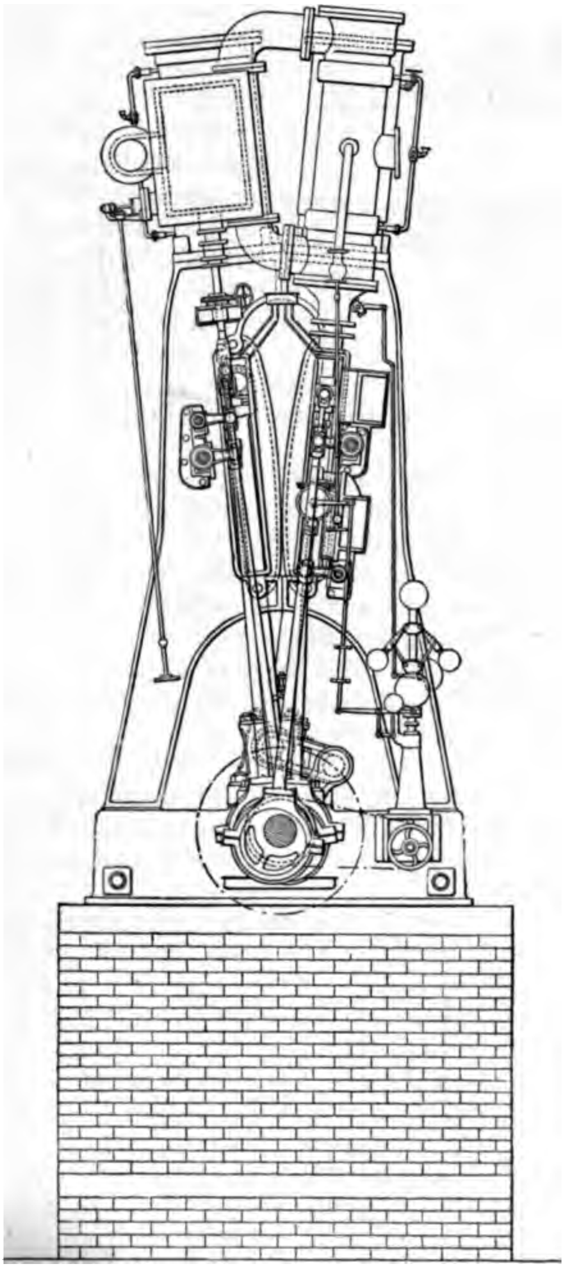


Fig. 828.—T. Bates & Co.: Vertical Condensing Steam Engine. Side Third Cylinder. Scale 1/48th.

diameter, working through double stuffing-boxes in the cylinder-covers. The stuffing-boxes are made double, as a safeguard, assisting the main



Bates & Co.: Vertical Triple-compound Condensing Steam Engine. Side Elevation, showing First and Second Cylinders. Scale 1/48th.

ng condensed steam. They are shown in section

t of the water to some extent hel

lubrication. The boxes are fitted with metal packing, consisting of white-metal rings, adjusted by means of brass circular gluts. Each ring is in two parts, cross-jointed and held by pins. Rings of fibrous packing are inserted: one in the first stuffing, two in the second.

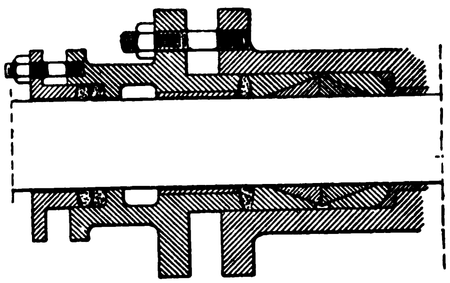


Fig. 830.—Bates' Vertical Engine: Metal Packing and Stuffing-boxes. Scale 1/8th.

The crosshead pins are of steel, 4 inches in diameter, 4¼ inches long, for bearing.

The power of the third cylinder is transmitted to the main shaft by means of a drag-link and crank, as shown in figs. 831, in preference to the method of a built or a solid crank-shaft. Such a connection is considered to be mechanically the superior, besides being more easily erected and dismounted. The cranks form the angle 45°.

The connecting-rods are 7½ feet long, or 4.29 times the length of the crank; 4 inches in diameter at the crosshead end, 4½ inches at the crank end, swelled to 5½ inches at the middle. The cranks are of wrought iron, turned, shrunk on the shafts; fitted with steel pins upon which the cranks are shrunk. The crank-pin for the third cylinder is 4½ inches in diameter, 5½ inches long. The main crank-pin—of the first and second cylinders—is 8 inches in diameter, 10½ inches long; of length sufficient to receive two connecting-rods, and of diameter to be sufficiently strong for resisting the stress on the overhung pin for the drag-link.

The crank-shafts, figs. 831, are of mild steel. The shaft for the third cylinder is 8 inches in diameter; the first and second cylinder shaft, or main shaft, is 12 inches in diameter, increased to 14 inches for the seat of the fly-wheel. The neck journal next the crank is 24 inches long; the outer journal is 10 inches in diameter, 20 inches long.

The fly-wheel is 18 feet in diameter, turned at the rim with grooves for 18 ropes 1⅝ inches in diameter; with holes for barring. The rim consists of ten segments. There are ten round arms turned to fit sockets in the boss or centre into which they are cottered. The arms are bolted to the rim with four 1¾-inch steel bolts and nuts. The joints of the rim are fastened with six 1¾-inch steel bolts and nuts. The total weight of the wheel is 20 tons.

The valve-gear is of wrought iron, except the pins, which are of steel. Every working joint and bearing throughout the engine is adjustable.

The engine is fitted throughout with lubricators for ensuring continuous running. The main-shaft bearings, figs. 831 and 832, are served by oil-pumps of the kind already noticed, page 463.

The condenser is a cubic casting of ⅞-inch metal, 5 feet high, 3 feet square, supplied with cold water from a 6-inch pipe through one side, having a 6-inch nozzle, from which the water is delivered upwards.

There are two single-acting air-pumps, of 1-inch metal; each 20 inches

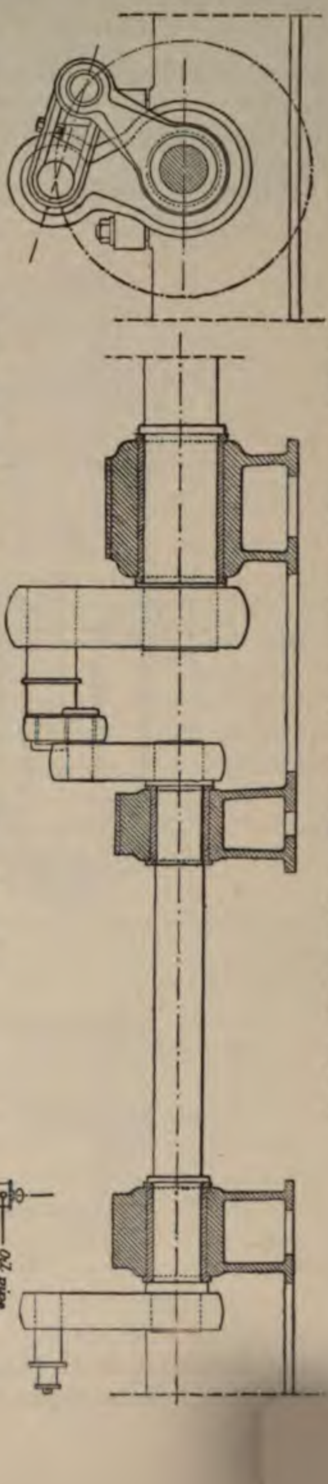
in diameter, with a stroke of 20 inches. They are worked by means of arms on a rocking-shaft, which is moved by a connecting-link from the crank-pin of the third cylinder. The plungers are fitted with metal packing at the upper part. The lower part has eight grooves turned in it for water-packing. The suction-valves and delivery-valves are clustered on a valve-seat for each. There are nine valves for each function, of india-rubber, 5 inches in diameter. All studs and nuts in contact with water are of phosphor-bronze. All parts are readily accessible.

The first cylinder has been constructed somewhat large proportionally, in order that the engine may be worked, when required, under reduced pressure; and that, under full pressure, the steam may be cut off proportionally earlier, and the admission may therefore be the more easily controlled by the governor.

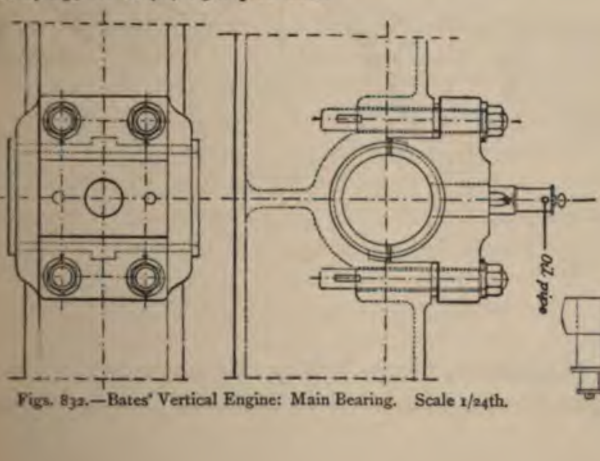
The governor is fitted with Collamore compensating tumbler weights, already noticed.

The engine stands on two cast-iron bases, of 1¼-inch metal, 24 inches high. The foundation is a solid mass of brickwork coped with stone, 17¼ feet by 9½ feet, and 7¼ feet deep, with an auxiliary foundation for the condenser and air-pumps.

The total height of the engine above the foundation is 19 feet. The total weight of the engine is 56 tons; and the price is £2725, or £48, 13s. per ton.



Figs. 831.—Bates' Vertical Engine: Main Shafts and Bearings, with Drag-link Connection. Scale 1/32d.



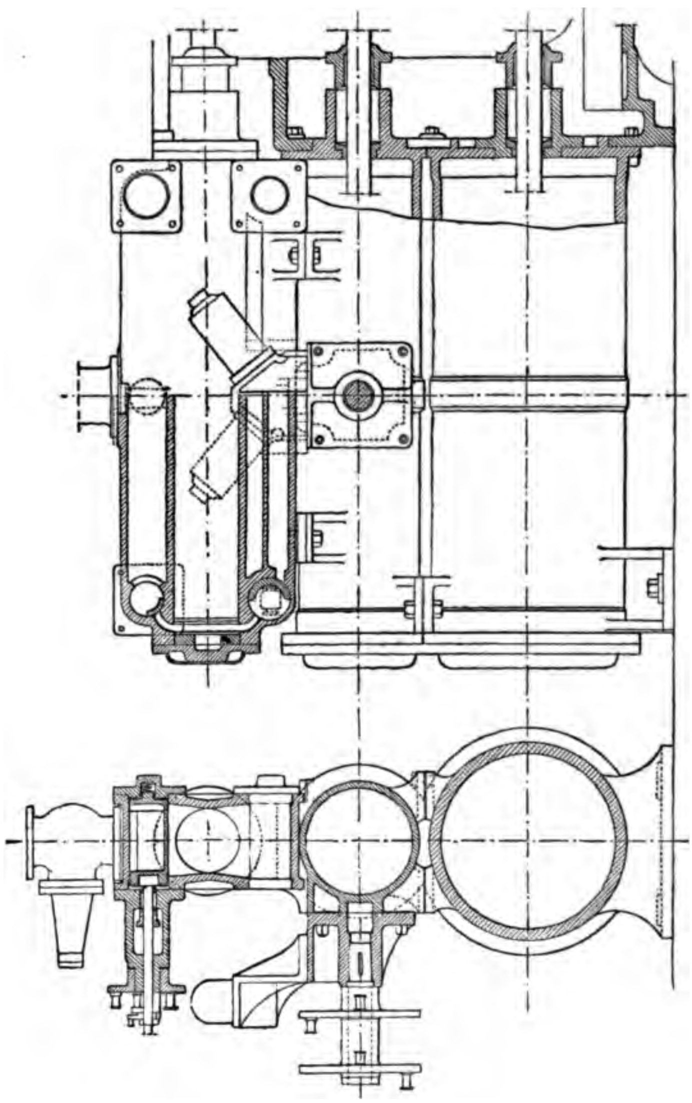
Figs. 832.—Bates' Vertical Engine: Main Bearing. Scale 1/24th.

CHAPTER LVIII.—HORIZONTAL TRIPLE-EXPANSION CONDENSING STEAM ENGINE.

DESIGNED BY MESSRS. RHODES & CRITCHLEY, BRADFORD; CONSTRUCTED BY MESSRS. COLE, MARCHANT, & CO., BRADFORD.

(Cylinders 8¼ inches, 13¼ inches, and 21½ inches in diameter; stroke 4 feet.)

This engine, figs. 835 and 836, was constructed for and erected at the

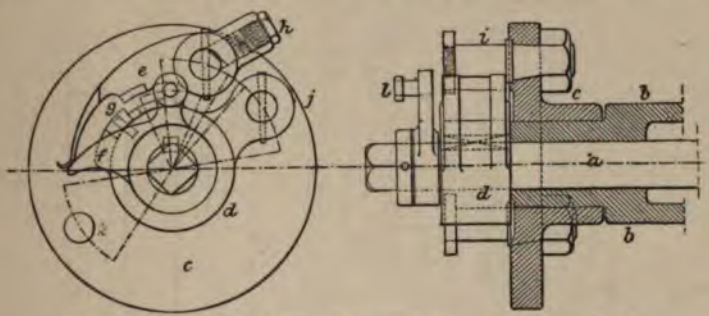


Figs. 833.—Rhodes & Critchley's Engine: Cylinders. Scale 1/24th.

mills of Messrs. R. & H. Hinchcliffe, Cragg Valley, Mytholmroyd. The peculiar design of the engine was an adaptation to the small area available

for housing the new engine—22 feet by 9½ feet—and the necessity for utilizing the existing foundations, that had been occupied by the previous engine.

The cylinders are 8¼ inches, 13¼ inches, and 21½ inches in diameter, with a stroke of 4 feet; having capacity-ratios of 1, 2.58, and 6.80. They are not steam-jacketed. They are placed horizontally one over the other, and the three piston-rods are fastened to one steel crosshead common to all, from which the power is delivered through a single connecting-rod to a crank on the main shaft. The first cylinder is fitted with Corliss valves,



Figs. 834.—Rhodes & Critchley: Triple-expansion Condensing Steam Engine.

Trip Gear: *a*, valve-spindle; *b*, valve-spindle guide, cast solid with valve-box bonnet; *c*, disc; *d*, bush keyed fast to valve-spindle; *e*, catch; *f*, cam for tripping catch; *g*, steel die; *h*, spring recoil box, to keep catch to its work; *i*, pin for catch; *j*, dashpot rod; *k*, rod from wrist-plate coupled to this pin; *l*, governor connection coupled to this pin.

for which the steam boxes are 4½ inches in diameter, 10 inches long; and the exhaust boxes are 5 inches in diameter. The trip gear (Rhodes and Bywater's patent) is shown in figs. 834. The discs are wrought-iron plates; the pawl is of steel, with a 1-inch steel pin. On the same axis are the cam and lever for tripping the pawl, also of steel, case-hardened. The wrist-plates are of cast iron bushed with steel liners, and fitted with 1⅜-inch steel case-hardened pins.

The second cylinder is fitted with two slides and cut-off plates worked directly by eccentrics on the drag-shaft, which is driven by a return-crank. The plates can be regulated by means of a hand-wheel and index to vary the cut-off, as may be required, in order to equalize the work of the cylinders. The third cylinder is fitted with an ordinary slide-valve, worked by an eccentric on the drag-shaft.

The pistons are on Buckley's system. The piston-rods are of steel, 3 inches, 3¼ inches, and 3½ inches in diameter respectively. The cross-head is of cast steel. It is fitted with a steel gudgeon 5½ inches in diameter. The slide-blocks are 2½ inches thick, and of length equal to the distance apart of the axes of the first and third cylinders. The connecting-rod is of scrap iron, 10 feet long, or five times the length of the crank, forked at t' ead end and solid at the crank end. The crank is of iron, 6 i with a 4¾-inch steel pin. The main shaft is of hammered s ches in diameter, increased to 10 inches for the fly-wheel; e 8½ inches in diameter, 14 inches long. The engine is

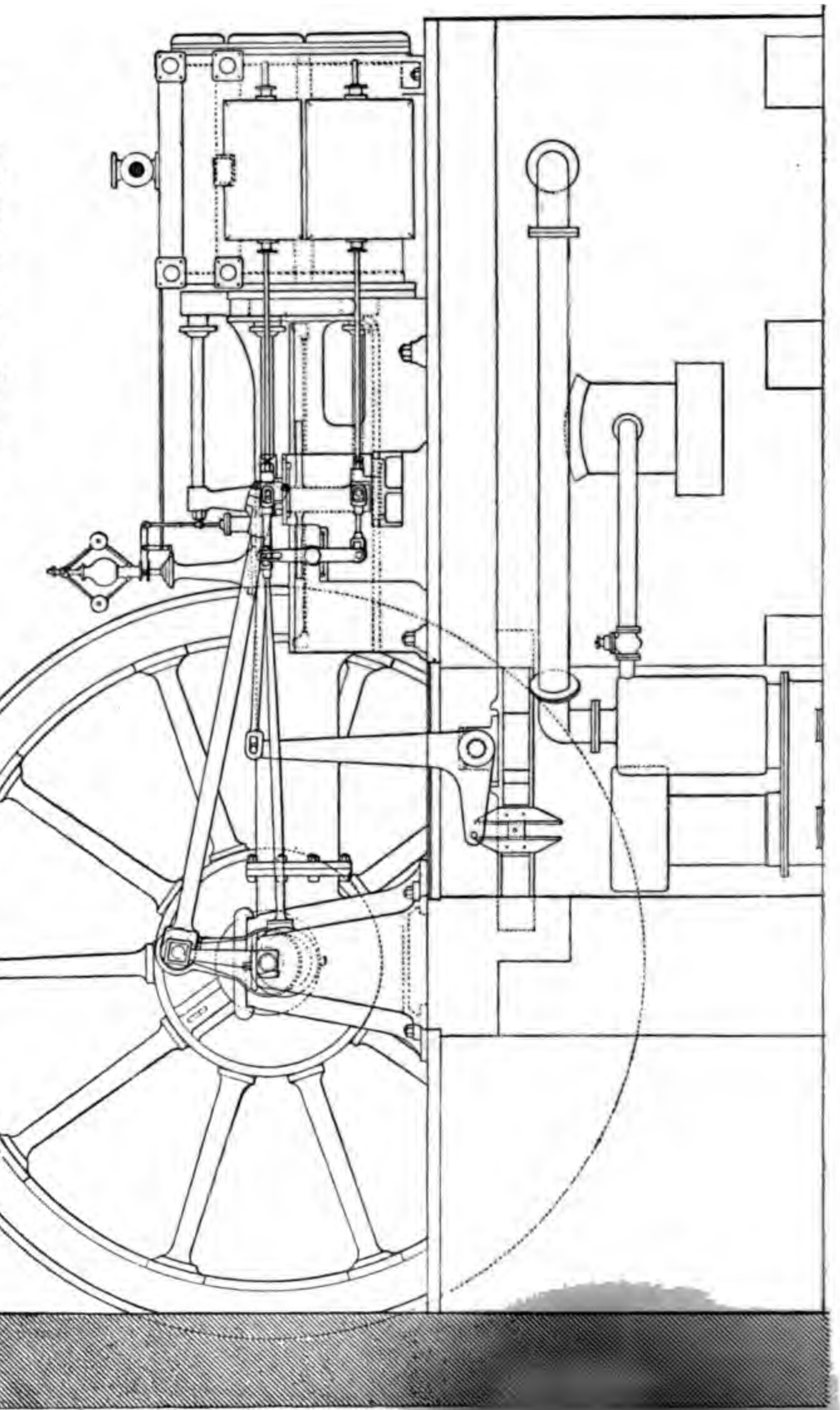


Fig. 835.—Rhodes & Critchley: Triple-expansion Condensing Steam Engine. Elevation. Scale 1/48th.

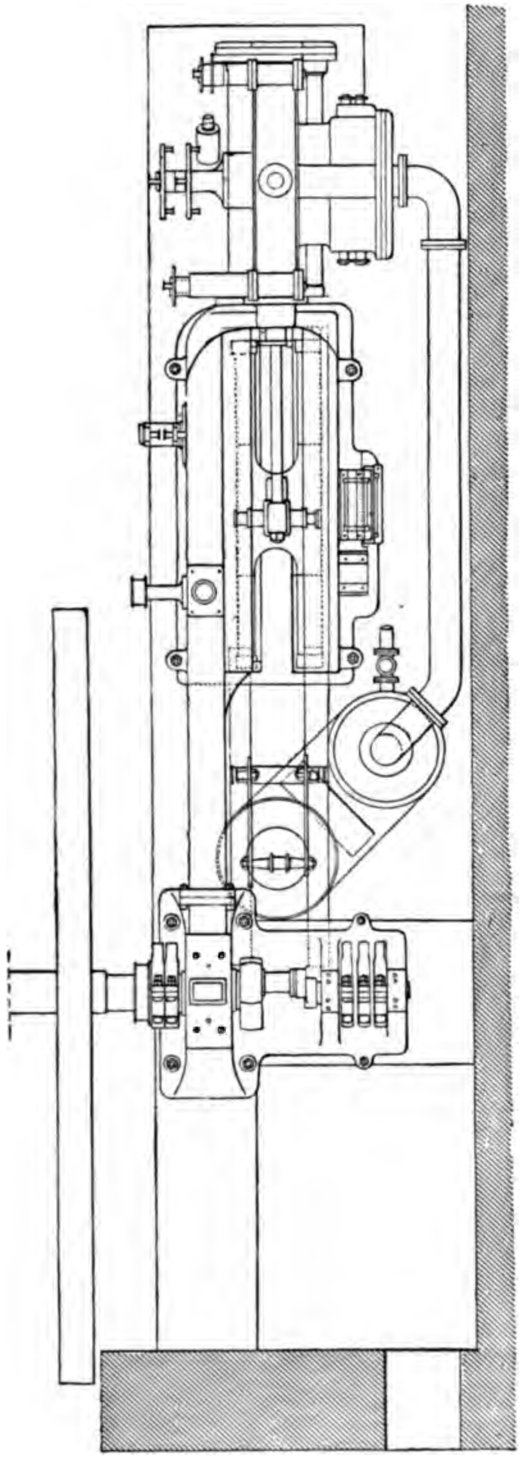
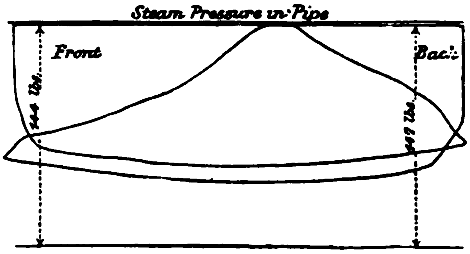


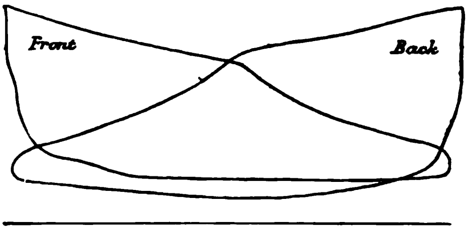
Fig. 836.—Rhodes & Critchley: Triple-expansion Condensing Steam Engine. Plan. Scale 1/48th.

controlled by a high-speed governor. The air-pump is 15½ inches in diameter, with a stroke of 18 inches, worked by means of a bell-crank lever, from the crosshead. There is a blow-through valve between the first and second cylinders, to get the stress fairly applied to the crosshead in starting.

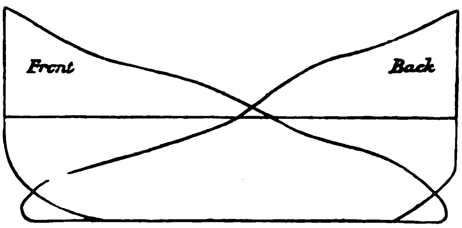
The indicator diagrams, figs. 837, were taken before the cylinders were lagged, for a speed of 63 revolutions per minute. They show 59.35, 60.05, and 68.20 respectively, indicator horse-power; making together 187.60 horse-power. The working pressure in the boiler was 150 lbs. per square inch.



First Cylinder. Scale of Pressure, 120 lbs. per inch.



Second Cylinder. Scale of Pressure, 48 lbs. per inch.



Third Cylinder. Scale of Pressure, 20 lbs. per inch.

Figs. 837.—Rhodes & Critchley's Engine: Indicator Diagrams.

According to the results of a test trial conducted by Mr. John Waugh, in November, 1889, the indicator horse-power was respectively 65.7, 54.6, and 59.1 for the several cylinders; making a total of 179.4 horse-power. The working pressure in the boiler was from 140 lbs. to 148 lbs. per square inch. The fuel used was half slack at 6*s.* 3*d.* per ton, and half "peas" at 7*s.* 9*d.* delivered. The feed-water was heated by an economizer. From the general performance of the engine it is estimated that 2.45 pounds of fuel was consumed at the trial per indicator horse-power per hour. The steam for cop-steaming and mill-heating was included in the work of the fuel; and is estimated as equivalent to from ¾ to 1 pound of coal, leaving from 1.70 to 1.45 pounds consumed by the engine per indicator horse-power per hour.

The weights of the engine are as follows:—

	Tons.	Cwts.	Qrs.	Lbs.
Bed-frame	0	102	3	6
Cylinders	0	76	3	14
Crosshead	0	7	1	12
Connecting-rod	0	8	1	0
Crank	0	8	0	18
Main shaft	0	15	1	20
Fly-wheel	12	0	0	0
Air-pump, eccentrics, rods, valves, bolts, &c., about	5	0	0	0
Total weight of engine	27	18	3	14

The price is £900, or £32, 4*s.* per ton.

CHAPTER LIX.

HORIZONTAL DISCONNECTIVE QUADRUPLE-EXPANSION NON-CONDENSING STEAM ENGINE, FOR 350 INDICATOR HORSE-POWER.

CONSTRUCTED BY MESSRS. RANKIN & BLACKMORE, GREENOCK.

(Cylinders 12 inches, 16 inches, 22 inches, and 28 inches in diameter; stroke 3 feet.)

This engine, figs. 838 and 839, was constructed for Messrs. James Bannatyne & Sons, and erected in April, 1889, at their City Rolling Mills, Limerick. The cylinders, four in number, are horizontal, and are arranged as for two engines, on two independent bed-frames, between which the fly-wheel is located. In ordinary condition the cylinders work in sequence, by successive expansions of the steam. But they are "disconnective," on Rankin's patent system; by means of which one half of the engine may be utilized, if the other half should happen to be out of order, or should break down.

The cylinders, figs. 840, 841, and 842, are successively 12 inches, 16 inches, 22 inches, and 28 inches in diameter, with a common stroke of 3 feet; and their capacity-ratios are as 1, 1.73, 3.36, and 5.45. They are not steam-jacketed; but they are covered with non-conducting material, lagged and varnished. They are bolted down to the bed-frames, each pair being placed in tandem. In the first pair—the first and second cylinders—the second is the outer cylinder; in the second pair, the third is the outer cylinder. Thus, the steam from the second cylinder is exhausted directly across to the third cylinder; thence to the fourth cylinder, and thence exhausted into the atmosphere. The disconnective system includes a special exhaust-pipe for the first half to the feed-heater, and a reducing valve to admit steam direct from the boiler to the second half. The normal speed of the engine is 75 revolutions, or 450 feet of piston per minute. The working pressure in the boiler is 180 lbs. per square inch.

The bed-frames are of box section, and are two complete rectangles. Each is formed in half lengths, bolted together. They are shown clearly in the foundation plan, figs. 845, and in section, figs. 842. They are 12 inches high; each box limb is 10 inches wide, of 7/8-inch metal; flanged to make a width of 11 inches at the base. The top width is increased to 15 inches for the bearings of the fly-wheel. The frame is planed on the lower surface, and on the upper facings for the cylinders, guide-bars, and pedestals.

The first and second cylinders are of 1 1/2-inch metal; the third and fourth are of 1 1/8-inch metal. They are each fastened with six bolts and nuts to the bed-frame. The first and second pistons are packed with Ramsbottom rings, of hard cast iron, 3/4 inch by 1/2 inch; the third and fourth are packed with Rowan's rings and springs. The piston of the third cylinder, 22 inches in diameter, is illustrated by figs. 843. The Rowan pistons are known as

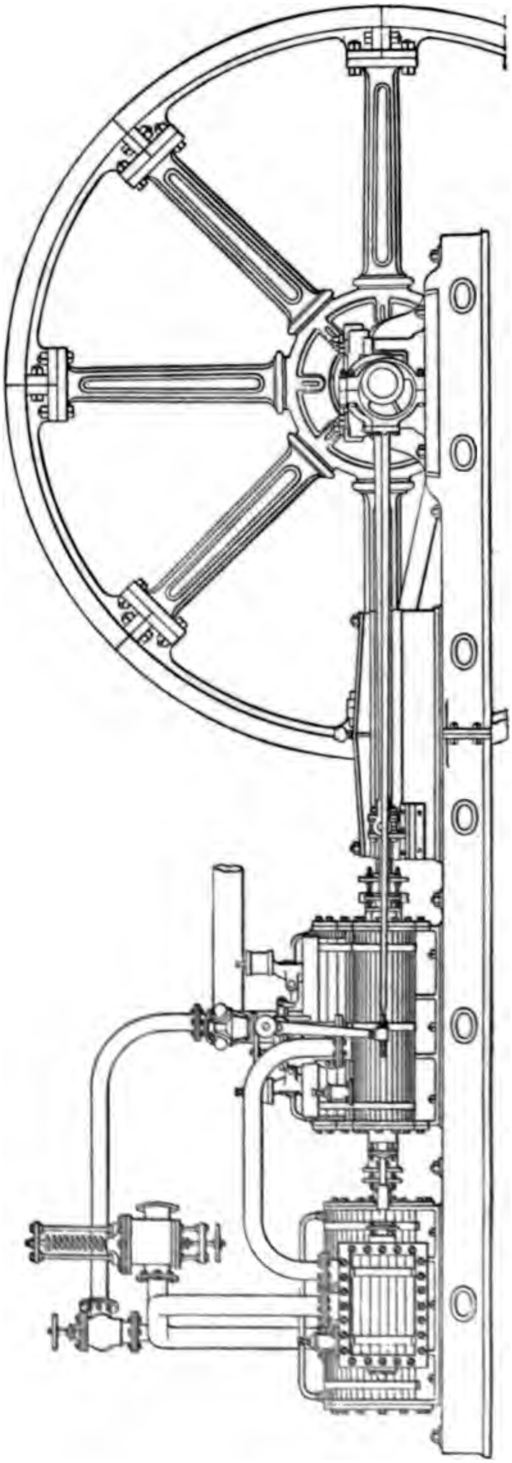


Fig. 838.—Rankin & Blackmore: Quadruple-expansion Non-condensing Steam Engine. Elevation. Scale 1/50th.

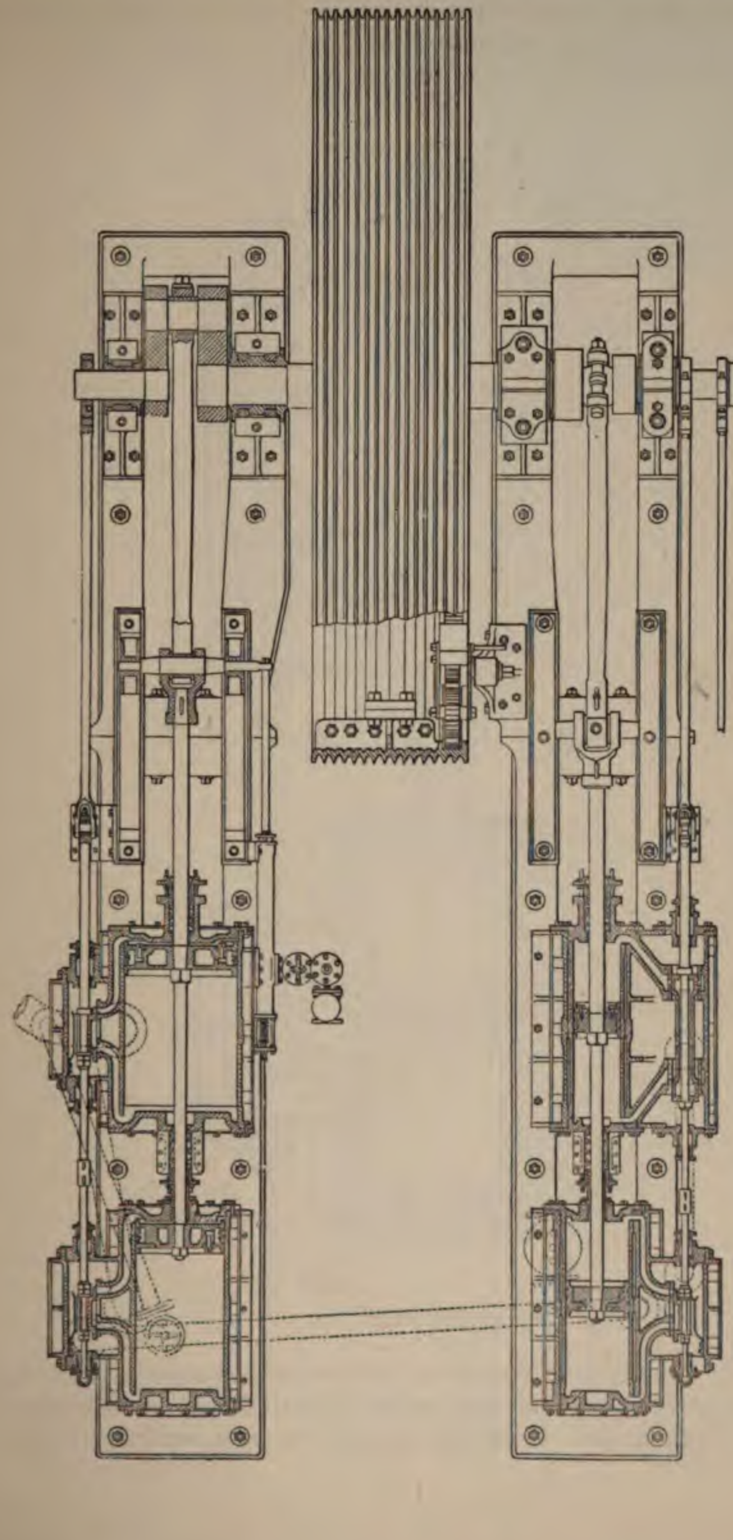


Fig. 839.—Rankin & Blackmore: Quadruple-expansion Non-condensing Steam Engine. Plan. Scale 1/50th.

solid-block pistons, as they are each cast one piece, recessed for the packing-rings. The recess is $1\frac{1}{8}$ inches deep, $3\frac{7}{8}$ inches wide, and is occupied by two cast-iron packing-rings, of uniform rectangular section, about $\frac{5}{8}$ inch

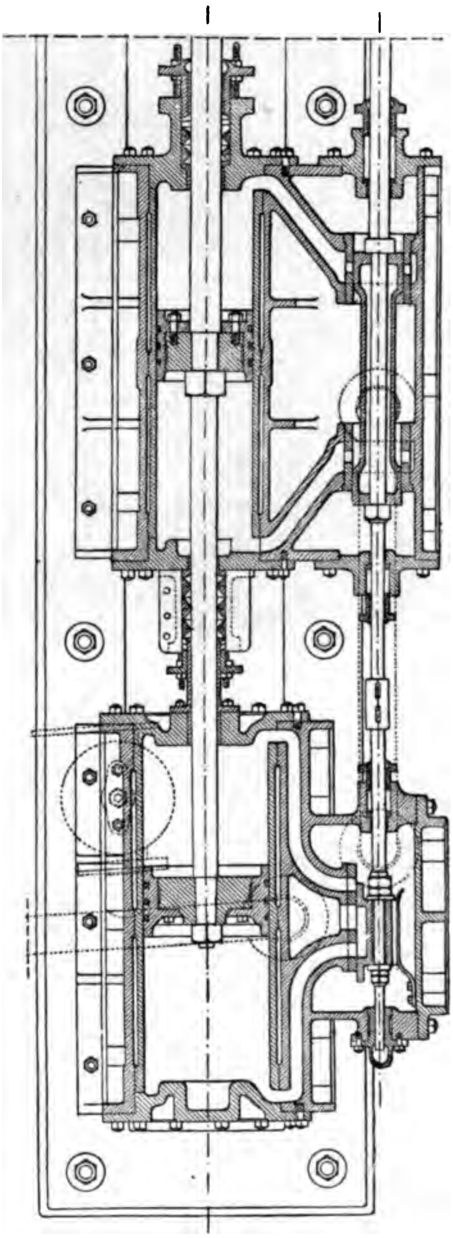


Fig. 840.—Rankin's Engine: First and Second Cylinders. Scale 1/24th.

by $\frac{7}{8}$ inch. The ends of each ring are made steam-tight by the aid of a brass glut, as shown, which is faced steam-tight to the top or the bottom, and the back of the recess. Each ring is acted on by a separate spring, con-

sisting of a steel ribbon bent to a circular form and closed by a coupling. On this ribbon, five studs or projections are cramped, which take a bearing on and press outwards on the back of the ring, in virtue of the distorted form

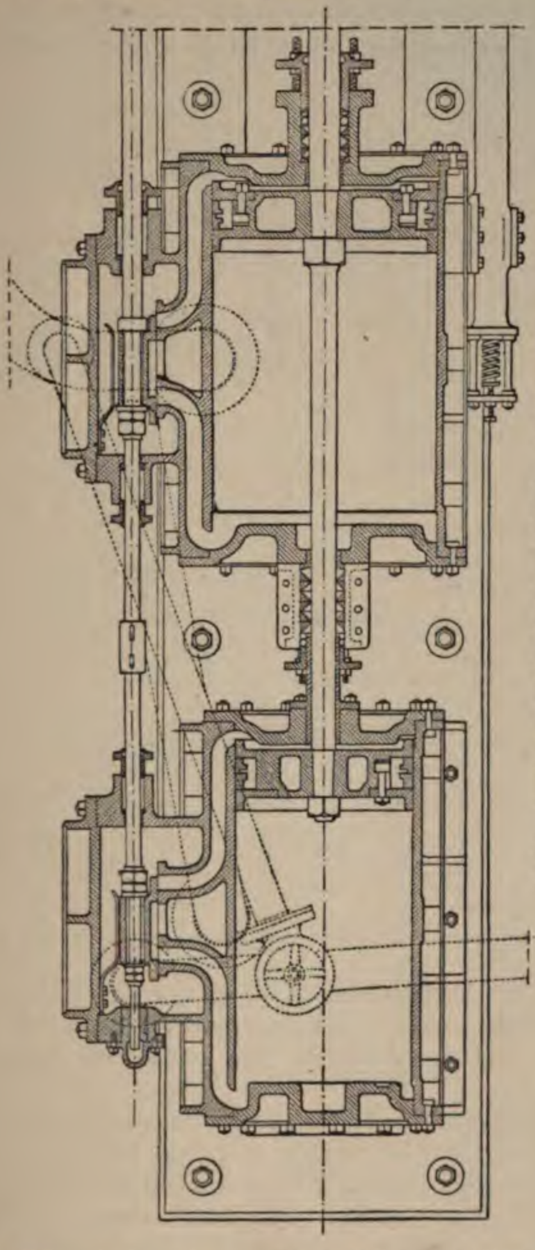
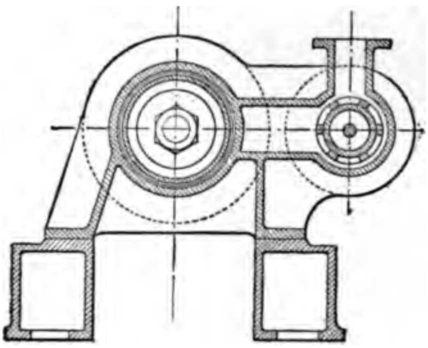


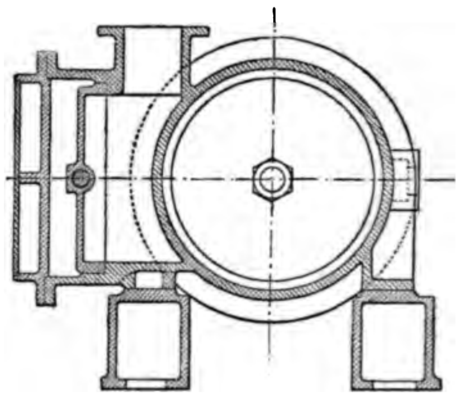
Fig. 841.—Rankin's Engine: Third and Fourth Cylinders. Scale 1/24th.

into which the ribbon is forced—a series of flat arcs of circles, corresponding to the number of bearing points. Thus the rings are constantly pressed against the inside of the cylinder. A third spring, consisting of a steel

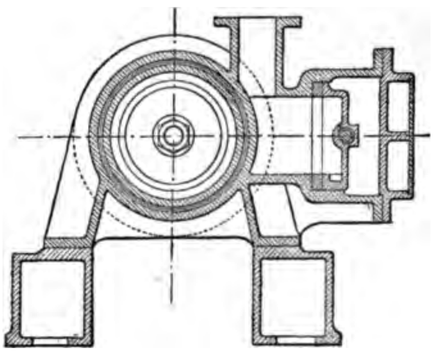
ribbon, is interposed between the two rings. It is of an undulating or corrugated form, and is known as the wave-spring. When in place, it is under stress, being slightly flattened, and it presses the two rings apart, causing them to bear steam-tight upon the top and bottom of the recess. The versed sine of each corrugation, when the spring is free, is ¼ inch. As



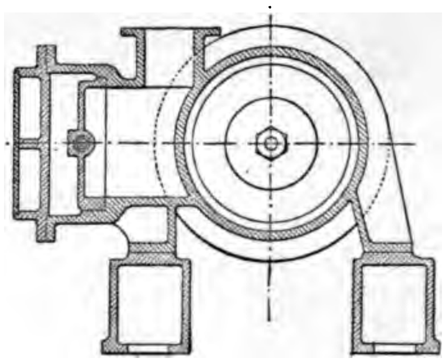
First Cylinder.



Fourth Cylinder.



Second Cylinder.



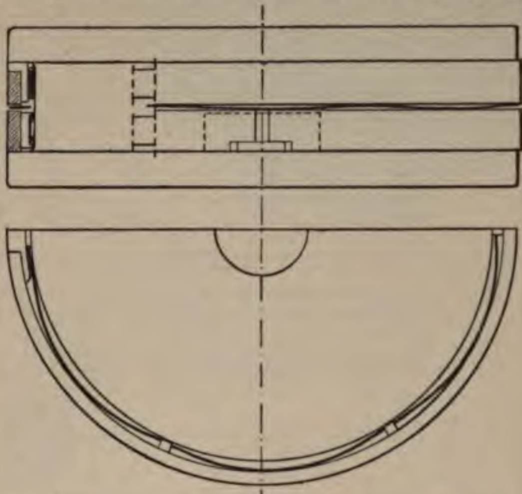
Third Cylinder.

Figs. 842.—Rankin's Engine: Sections of Cylinders and Valves. Scale 1/24th.

each spring can, by this combination, be adjusted for its own special duty, independently of the others, minimum pressures are exerted on the inside of the cylinder and the recess of the piston, consistent with steam-tightness.

The first cylinder is fitted with Proell's automatic expansion gear and governor for cutting off (described at page 74), constructed by Messrs. T. M'Culloch & Sons, Kilmarnock. But, instead of following Proell's general practice of providing two Corliss valves for exhausting the steam, Messrs. Rankin & Blackmore devised piston-valves on one spindle, worked directly from an eccentric on the main shaft, shown in fig. 840; the valve-spindle being extended to meet the valve-spindle of the second cylinder, to which it is cottered. Thus, by one eccentric, the first and second cylinders are

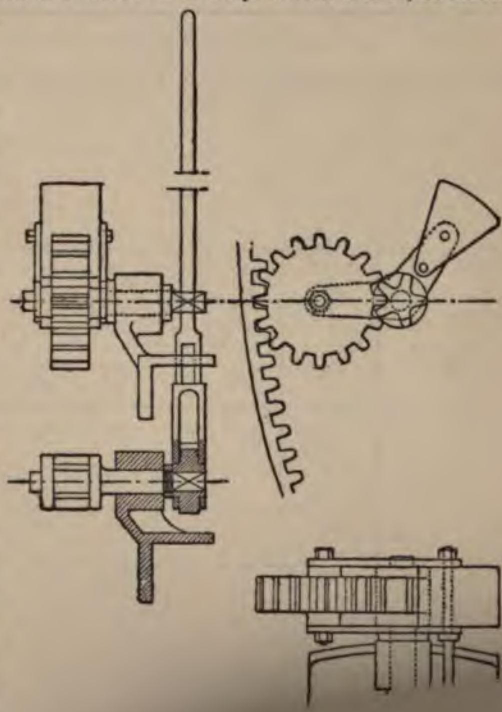
served; and by a like combination the third and fourth are served by another eccentric, as shown in the general plan, fig. 839, and the detail plans. Between the first and second cylinders, and between the third and fourth, there is only one stuffing-box for the piston-rod, in halves bolted together.



Figs. 843.—Rankin's Engine: 22-inch Rowan Piston. Scale 1/8th.

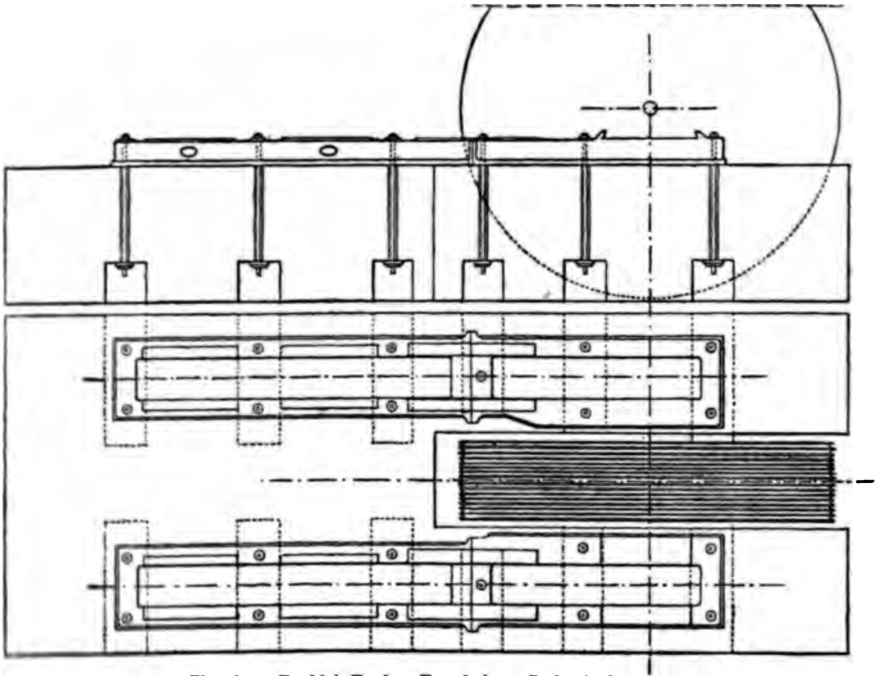
The piston-rods are of forged iron, fitted into the pistons and crossheads, with a good taper and a shoulder; secured by a deep nut on the pistons, and a wrought-iron cotter on the crosshead. The gudgeons are of scrap iron, tightly shrunk into the crossheads. These are fitted with adjustable slides, of hard cast iron, which work in adjustable cast-iron guides.

The connecting-rods are of scrap iron. The gudgeon ends are fitted with brass bushes secured by gibs and cotters; the crank-pin ends are T-shaped, fitted with flat bushes of hard brass, with liners between the bushes for adjustment; secured by wrought-iron covers, and bolts and nuts recessed into guard rings having set-pins.



Figs. 844.—Rankin ß

The main shaft is built of scrap iron, with two double-arm cranks, set on the shaft at right angles to each other. The shaft is 10 inches in diameter at the inner journals, and 7½ inches at the outer journals. The pedestals for the main bearings, four in number, are bolted to the bed-frames; they can be adjusted by means of wedge-form keys. They are fitted with gun-metal bushes, each in four p



Figs. 845.—Rankin's Engine: Foundation. Scale 1/96th.

taken up in any direction. To facilitate such adjustment, two bolts having wedge ends are passed through the covers, and can be tightened with deep nuts. The covers of the pedestals are of tough cast iron, and they are each fastened with four bolts and nuts.

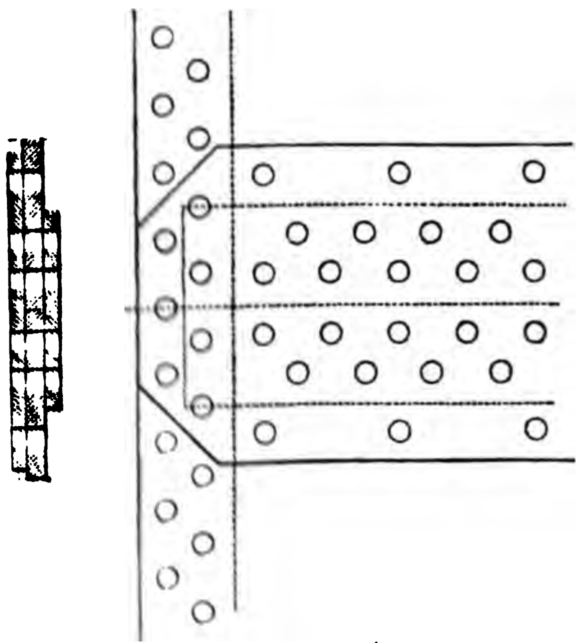


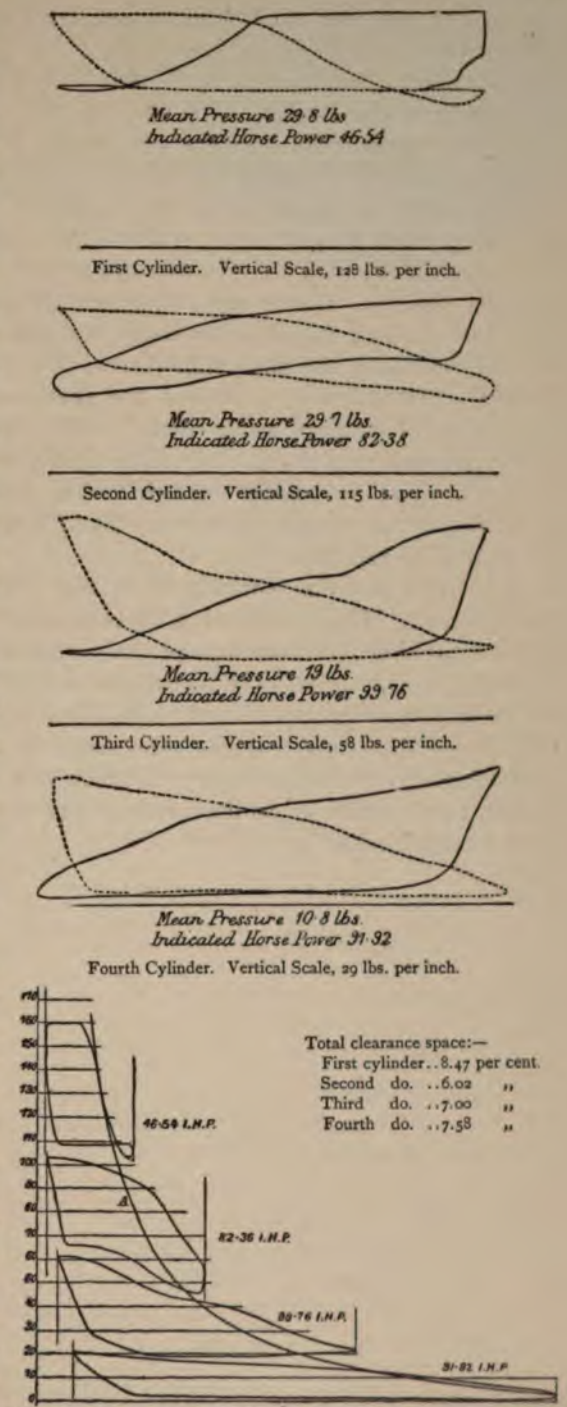
Fig. 846.—Rankin & Blackmore's Engine: Riveting of Boiler. Scale 1/12th.

The fly-wheel is 16 feet ¾ inch in diameter, 3¼ feet wide at the rim. The rim is in eight segments, bolted together and to the arms. The arms are eight in number, keyed into the rim, and cottered into the centre, which is 4 feet in diameter. The rim is turned with fifteen grooves suitable for hemp ropes, 5¼ inches in circumference—about 1⅝ inches in diameter. The wheel is fastened on the shaft with four keys.

A barring engine is supplied for starting or turning the fly-wheel, as shown in fig. 839, and also in the detail, figs. 844. It is scarcely ever employed except when there is no steam at command. By giving steam through the stop-valve, on the first piston, or through a reducing-valve on the third piston, the engine is easily started. When employed, the barring engine is thrown into gear and worked by means of the hand-lever. Then it is thrown out of gear and is kept out by means of the balance weight.

The feed-pump is 2 inches in diameter, with a stroke of 3 feet; worked off the fourth crosshead; connected by copper pipes to the boiler and the feed-water. The heater is on Atkinson's system; the temperature of the feed can be raised 190° F.

The foundation for the engine, figs. 845, is of concrete, 5 feet 10 inches deep, 35 feet 8 inches long, by 14 feet wide; recessed for the fly-wheel. Each bed-frame is fastened down with eleven 1½-inch iron bolts and nuts, with cotters 2 inches by 5/16 inch at the lower ends, and cast-iron washer-plates, 9 inches square, 2 inches thick. Holes 3 inches square are formed in the concrete to receive the bolts. Transverse open-



First Cylinder. Vertical Scale, 128 lbs. per inch.

Second Cylinder. Vertical Scale, 115 lbs. per inch.

Third Cylinder. Vertical Scale, 58 lbs. per inch.

Fourth Cylinder. Vertical Scale, 29 lbs. per inch.

Block Diagram for Four Cylinders. A, Hyperbolic Curve. 320.6 I.H.P.

Figs. 847.—Rankin's Engine: Indicator Diagrams.

ings in the concrete, 21 inches square, are formed at the bottom, to give access to the bolts.

The boiler, constructed by Messrs. Rankin & Blackmore, for supplying steam to the engine, is of steel, of the return-tube marine type, for a working pressure of 180 lbs. per square inch. It is $11\frac{1}{2}$ feet in diameter, 9 feet 8 inches long, having two of Fox's corrugated furnace-tubes, 3 feet 5 inches in diameter, giving a total heating surface of 1220 square feet, or 29 times the grate-area, which is 42 square feet. The shell-plates are $1\frac{1}{8}$ inches thick; they were rolled cold in order to obviate the risk incurred by local heating. There are 166 tubes $3\frac{1}{2}$ inches in diameter inside, at $4^{11}/_{16}$-inch pitch, 6 feet 8 inches long. Of these, 52 are stay-tubes, screwed into the front and the back tube-plates, thus superseding the employment of nuts. The circular seams of the shell are double-riveted; and the longitudinal seams are triple-riveted, made with butted joints and straps $1^5/_{16}$ inches thick, as in figs. 846. The shell-rivets are of steel, $1\frac{1}{4}$ inches in diameter. The rivet-holes were drilled in position, and the riveting was performed with hydraulic pressure. The percentage of strength of plates is 84; that of rivets, 86.

After two months' working night and day the engine was tested for performance. The results of a three-hours' test, conducted by the proprietors, making 75 revolutions per minute, and indicating 350 horse-power, showed a consumption of 1.65 pounds of Welsh coal of good quality, per indicator horse-power per hour. Sample diagrams are shown in figs. 847. It is stated that these engines consume only about one-half as much fuel as the engine previously employed, which was a compound non-condensing engine, using steam of 80 lbs. pressure per square inch, generated by two large Lancashire boilers.

RAILWAY LOCOMOTIVES.

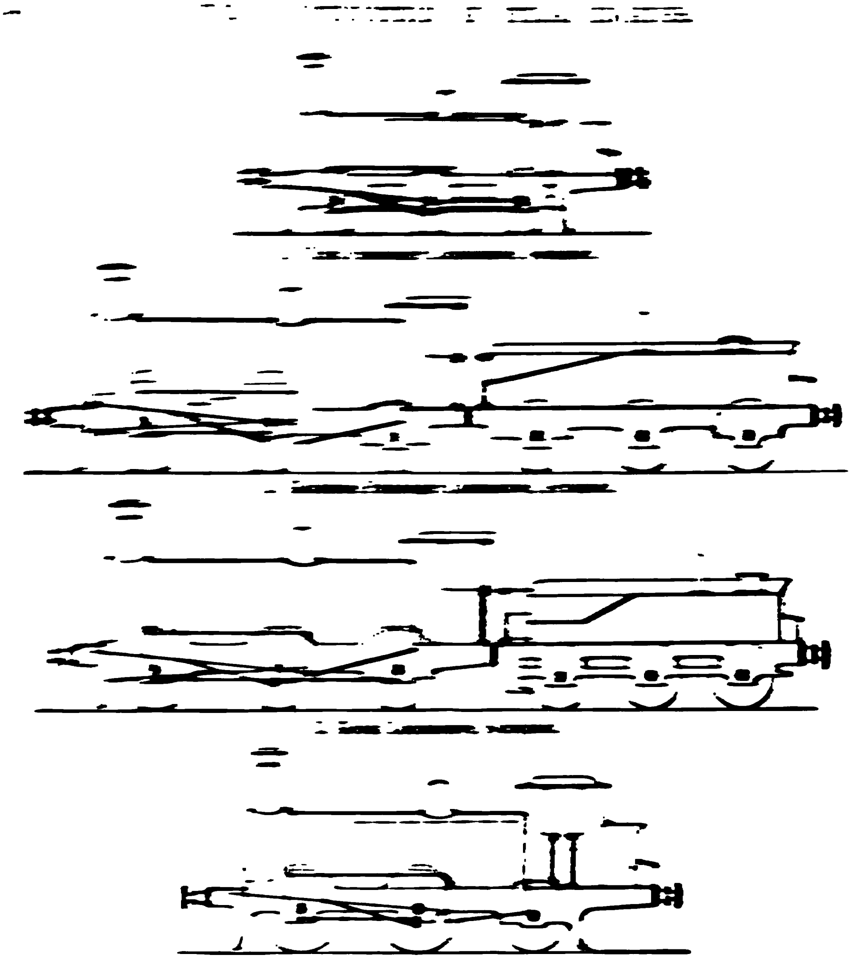
CHAPTER LX.—BRITISH AND FOREIGN TYPES OF LOCOMOTIVES.

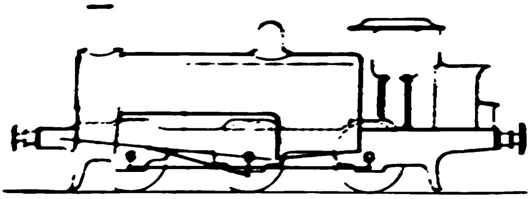
As a system of types or classes of locomotives for a first-class English railway, diagrams of those designed and constructed by Mr. William Stroudley for the service of the London, Brighton, and South Coast Railway are given in figs. 848.[1] Leading dimensions and weights for each class are given in the table 175, page 489, comprising engines weighing from 24½ tons to upwards of 40 tons; or, with tender, about 68½ tons gross. The Gladstone passenger class is distinguished by the coupling of the leading wheels to the drivers. This engine is afterwards noticed.

American practice, many years since, arrived at one leading type of passenger engine, which serves also as a light freight engine—in fact a type universally employed in the States—having eight wheels, of which four in front are framed in a bogie, and the four wheels behind are coupled drivers. There are, for passenger and goods traffic, four principal types of locomotives:—the passenger or light freight locomotive having four-coupled wheels with a leading bogie, just noticed; goods engines, having six-coupled wheels, with a leading bogie, or with a pony-truck or single radiating pair of wheels in front—of the "Mogul" type; heavy goods engines, "Consolidation" type, having eight-coupled wheels, and a pony-truck in front; and four-coupled wheel switching, shunting, or marshalling engines. The cylinders are, in all types, outside. The following table, No. 176, page 492, gives dimensions, weights, and weight of trains, for types of American locomotives constructed by the Baldwin Locomotive Company, illustrated by figs. 849 and 850.

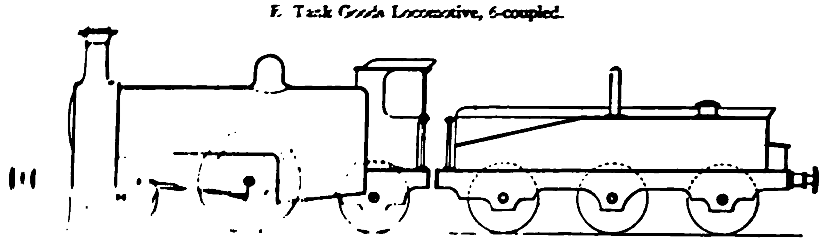
Each of the types named in the table is constructed of several sizes, of which the largest is the size noted in the table. No. 1, the "American" type, is suited for ways laid with rails of from 30 lbs. to 40 lbs. per yard. No. 2, "American," for passenger and freight traffic; for burning anthracite, a longer fire-box is required, adding from 4000 to 5000 pounds to the weight of the engine. No. 3, fast passenger locomotive:—the weight on the driving-wheels can be increased by the addition of from 8000 to 10,000 pounds by shifting the bearings on the equalizing beams between the trailing and the driving axles. No. 4, for freight and mixed traffic; for burning anthracite the engine is increased in weight by about 6000 pounds. The leading and trailing coupled wheels can be flanged, the driving wheels plain, and the truck or bogie made with a swinging bolster; or the driving and

[1] See a paper by Mr. Stroudley on "The Construction of Locomotive Engines, with some results of the working of those on the London, Brighton, and South Coast Railway," in the *Minutes of Proceedings of the Institution of Civil Engineers*, vol. lxxxi., 1884–1885, page 76.





E. Tank Goods Locomotive, 6-coupled.



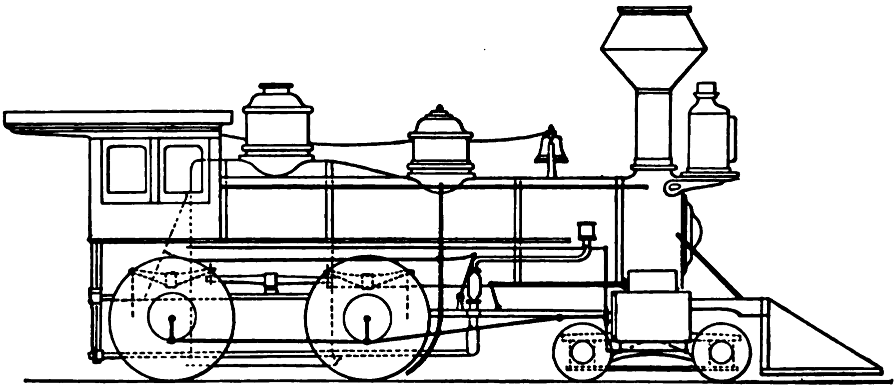
H. Passenger Locomotive, Single.

[illegible] Brighton and South Coast Railway: Types of Locomotives, by Mr. William Stroudley.
Scale 1/144th

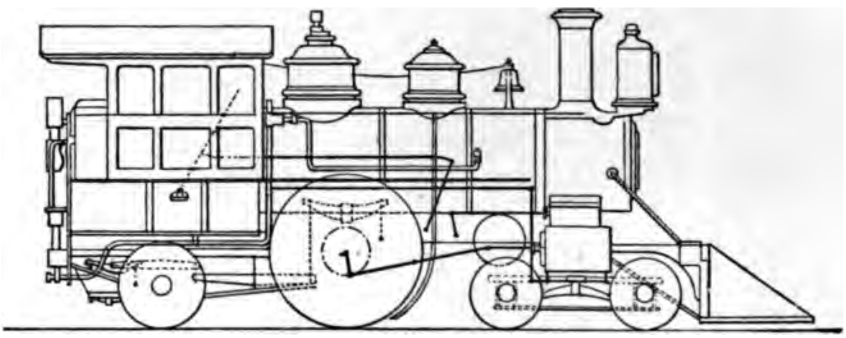
Table No. 175.—Locomotive Stock of the London, Brighton, and South Coast Railway. 1885.

Class.	Locomotive.											Tender.		Locomotive and Tender.		
	Cylinders.		Diameter of Driving Wheels.	Wheel-base.	Area of Fire-grate	Area of Heating Surface.	Ratio.	Weight in Working Order.				Weight, with 2 tons of coal and 10 tons of water.	Capacity of Tank.	Total Length.	Weight in Working Order.	
	Diameter.	Stroke						Leading.	Driving.	Trailing.	Total.				Maximum	Average.
	inches.	inches.	feet.	feet. ins.	sq. feet.	sq. feet.	ratio.	tns. cwt.	tons. cwts.	tons. cwts.	tons. cwts.	tons. cwts.	gallons.	ft. ins.	tons. cwts.	tons. cwts.
A. Tank passenger, 6-coupled,	13	20	4	12 0	10	506.16	50.62	8 5	8 2	8 0	24 7	—	500	26 ½	—	—
B. Gladstone passenger, 4-coupled,	18¼	26	6½	15 7	20.65	1492.10	72.25	13 16	14 10	10 8	38 14	27 7	2250	51 10	66 1	60 1
C. Goods, 6-coupled, ...	18¼	26	5	15 3	20.95	1413.00	67.45	13 14	14 0	12 13	40 7	28 0	2550	49 8	68 7	—
D. Tank passenger, 4-coupled,	17	24	5½	15 0	15.30	1035.91	67.71	13 10	13 10	11 10	38 10	—	860	31 7½	—	—
E. Tank goods, 6-coupled, ...	17	24	4½	15 3	15.30	1031.93	67.45	13 10	13 10	12 10	39 10	—	900	32 4½	—	—
G. Passenger, ... single, ...	17	24	6½	15 11	17.04	1184.31	69.50	12 0	13 10	7 18	33 8	27 7	2250	50 11	60 15	—

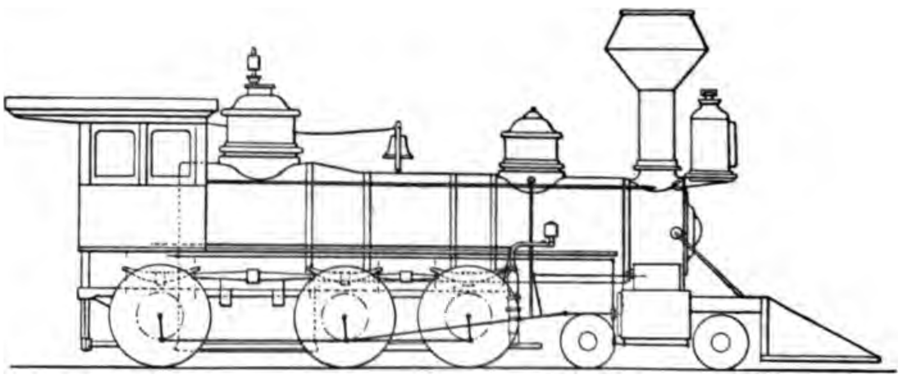
Note to Table.—The uncoupled engine wheels and the tender wheels are 4½ feet in diameter.



No. 2. Passenger and Freight Locomotive, "American" type.

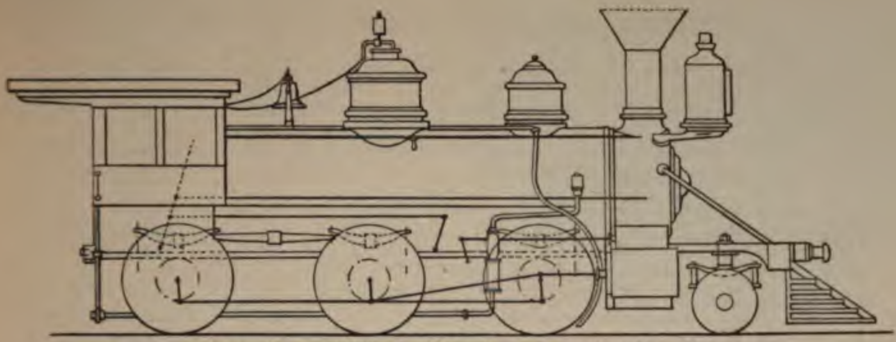


No. 3. Fast Passenger Locomotive.

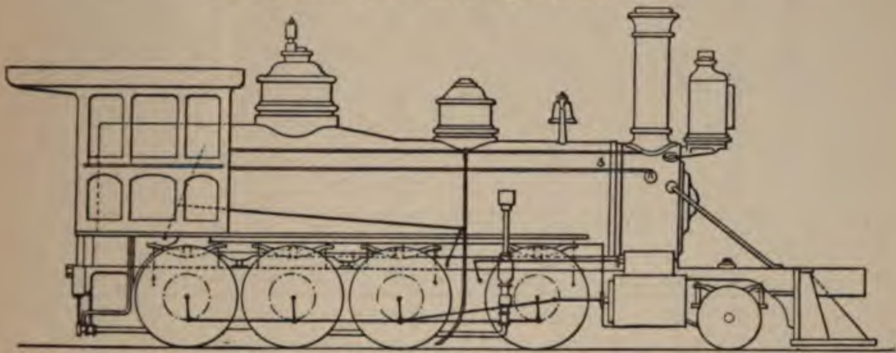


No. 4. Ten-wheel Freight and Mixed Traffic Locomotive.

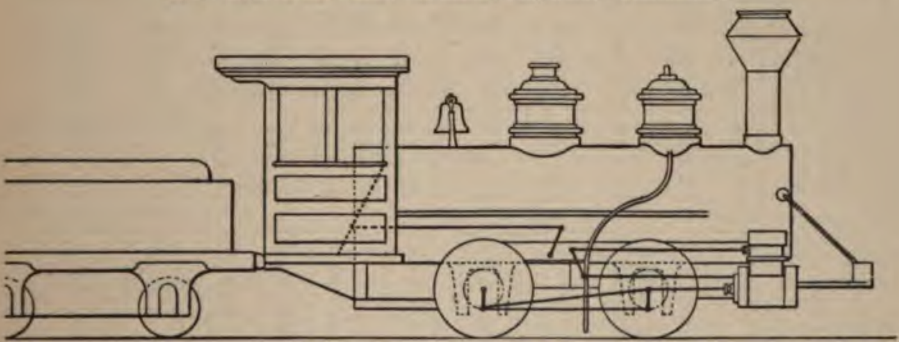
Figs. 849.—Types of America cale 1/100th.



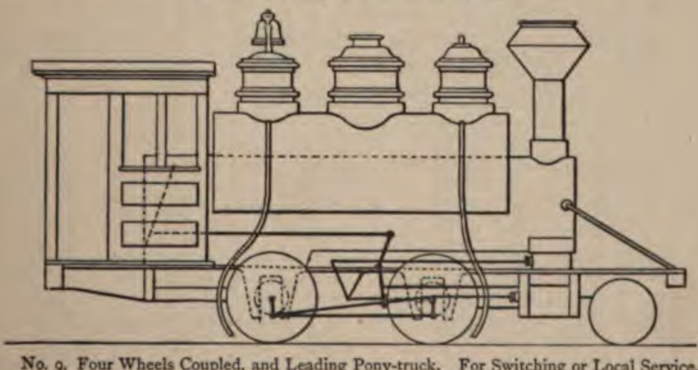
No. 6. Six-coupled Wheels, with Leading Pony-truck: "Mogul."



No. 7. Eight-coupled Wheels, with Leading Pony-truck: "Consolidation."



No. 8. Four-coupled Wheels: Switching.



No. 9. Four Wheels Coupled, and Leading Pony-truck. For Switching or Local Service.

Figs. 850.—Types of American Locomotives (continued). Scale 1/100th.

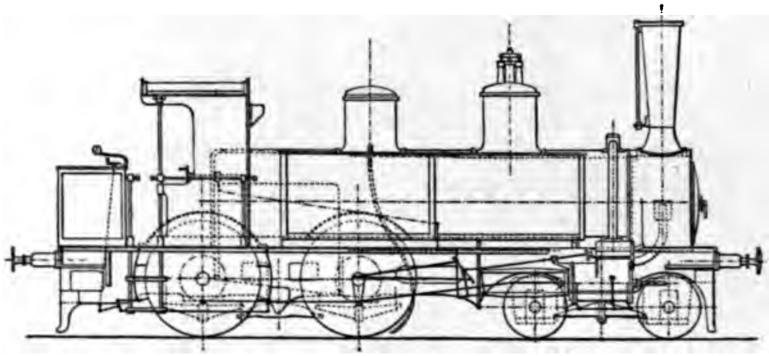
Table No. 176.—TYPES OF AMERICAN LOCOMOTIVES; 4-FEET-8½-INCH GAUGE.

Designation and Type of Locomotive.	Disposition of Wheels.	Cylinders: Diameter and Stroke.	Driving Wheels: Diameter.	Wheel-base. Driving.	Wheel-base. Total.	Wheel-base. Total, including Tender.	Weight in Working Order. Driving.	Weight in Working Order. Total.	Reputed Weight of Train on Level.
		ins. ins.	inches.	ft. ins.	ft. ins.	ft. ins.	tons. cwts.	tons. cwts.	tons.
1. Light passenger, "American".........	4-coupled wheels, with bogie...........	12 × 24	48 to 54	6 6	19 1	4-wheel tender, 38 11	13 8	20 11	860
2. Passenger and freight, "American".........	Do. do. ...	18 × 24	61 to 66	8 6	22 5	8 do. do. 43 0	21 18	33 1	1400
3. Fast passenger........	Single driving wheels, with bogie and trailing wheels...........	18 × 24	72 to 78	—	21 1	—	16 1	37 10	1280
4. Freight and mixed traffic, "Ten-wheel"	6-coupled wheels, with bogie...........	19 × 24	54 to 60	13 6	23 8	8-wheel tender, 44 9	28 11	37 10	1855
5. Light freight, "Mogul"...	6-coupled wheels, with leading radial pony-truck...........	14 × 18	37 to 41	11 0	17 0	Do. 36 0	17 17	21 9	1160
6. Freight, "Mogul"......	Do. do. ...	19 × 24	54 to 60	15 2	22 6	Do. 43 4	30 16	36 12	2000
7. Freight, "Consolidation".................	8-coupled wheels, with leading pony-truck	20 × 26	48 to 50	14 9	22 10	Do. 47 10	41 19	48 4	2740
8. Switching	4-coupled wheels......	16 × 24	43 to 49	7 6	7 6	—	25 0	25 0	1635
9. Switching and local service..............	4-coupled wheels, with leading pony-truck	15 × 24	43 to 49	7 4	14 9	—	19 13	23 4	1280
10. Do. do. "Forney"	4-coupled wheels, with trailing pony-truck	15 × 24	43 to 49	7 0	15 3	—	21 0	26 16	1380
11. Do. do. "Forney"	4-coupled wheels, with trailing bogie......	17 × 24	49	7 6	20 9	—	25 18	33 10	1700
12. Do. do. "Double-ender"..............	4-coupled wheels, with pony-truck at each end..................	17 × 24	49 to 55	7 6	22 10	—	23 4	32 3	1525
13. Local passenger service, "Double-ender"	4-coupled wheels, with leading pony-truck and trailing bogie	16 × 24	55 to 61	8 6	30 1	—	20 2	37 10	1310
14. Switching and freight	6-coupled wheels.......	19 × 24	49	11 0	11 0	—	34 17	34 17	2280

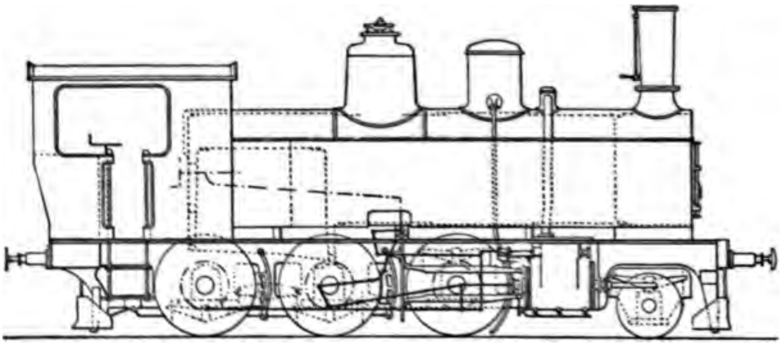
trailing wheels can be flanged and the leading pair plain, but the truck should be without the swinging bolster. A straight-top boiler, having a dome in the middle, is made for locomotives of this pattern. No. 5, light-freight engine, "Mogul" type, for rails weighing 40 lbs. per yard. No. 6, freight engine, "Mogul" type: the leading and trailing coupled wheels have flanged tyres; the driving wheels are plain. The pony-truck has a swinging bolster, and by means of a radius bar, it radiates on a point in advance of the leading coupled axle. No. 7, "Consolidation" type: it has two pairs of flanged coupled wheels—either the leading and trailing, or the driving and trailing—the two other pairs being without flanges. The pony-truck has a swinging bolster and radius bar, as in the "Mogul" type. No. 8, switching engine: the weights and loads are calculated for engines with separate tenders. No. 9, for switching or local service, having the driving axle under the fire-box, has a shallow fire-box. Two pairs of wheels are equalized together longitudinally; either the driving and coupled wheels, or the coupled wheels and pony-truck. The pony-truck has a swinging bolster and radiating bar. This engine, running with the truck ahead, can readily traverse the quickest curves. No. 10, specially adapted for switching and local service, and for short runs at moderate speed. The fuel and water are carried on and in the tank at the back of the engine. The pony-truck is under the tank, and has a swinging bolster and radius bar. The loads on the coupled wheels are equalized together, the boiler and machinery being carried on equalizing levers midway between the axles. On this system of engine there is room for a large fire-box of ample length and width. No. 11, also of the Forney type, having a trailing bogie, has the characteristics of No. 9, with a trailing pony-truck. But with the bogie, the capacity of the tank is greater than in No. 9, and the engine runs somewhat more smoothly. It is like the "American" type, No. 2, as it is carried on two systems of equalized wheels. In No. 12 type, each pair of coupled wheels is equalized with the neighbouring pony wheels. Each pony-truck has a swinging or sliding bolster and radius bar. Such engines pass freely along short curves, and are specially adapted for light switching service, or for light passenger or freight traffic on city or suburban railways, where short curves are traversed at some speed, and where it is desirable to run both ways without turning the engine. No. 13 is adapted for service like that mentioned for No. 12. The bogie under the tank admits of a larger tank than for No. 12, and has a greater capacity for water and fuel. No. 14 has the driving and trailing coupled wheels equalized, and they carry their load at the centres of the side-equalizing beams. The springs of the leading coupled wheels are cross-equalized. The driving wheels have plain tyres.

The locomotive stock of the St. Gothard Railway is typical of European practice for mountain traffic. The cylinders are outside; and the five classes or types are illustrated by figs. 851 and 852, and their principal dimensions are given in table No. 177, page 496.

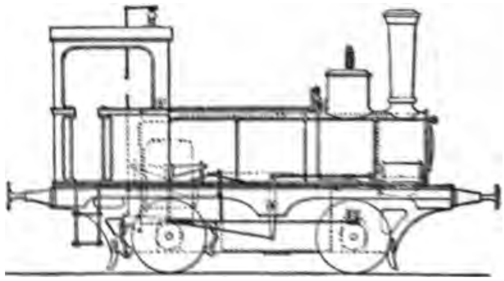
The tank engine, B′, is a powerful engine for passenger traffic, of four coupled wheels, with a leading bogie, resembling the American engines, already described; designed to work high-speed trains on easy inclines



B′. Passenger Tank Locomotive.



C′. Tank Locomotive, six-coupled, for Passenger and Goods Traffic.

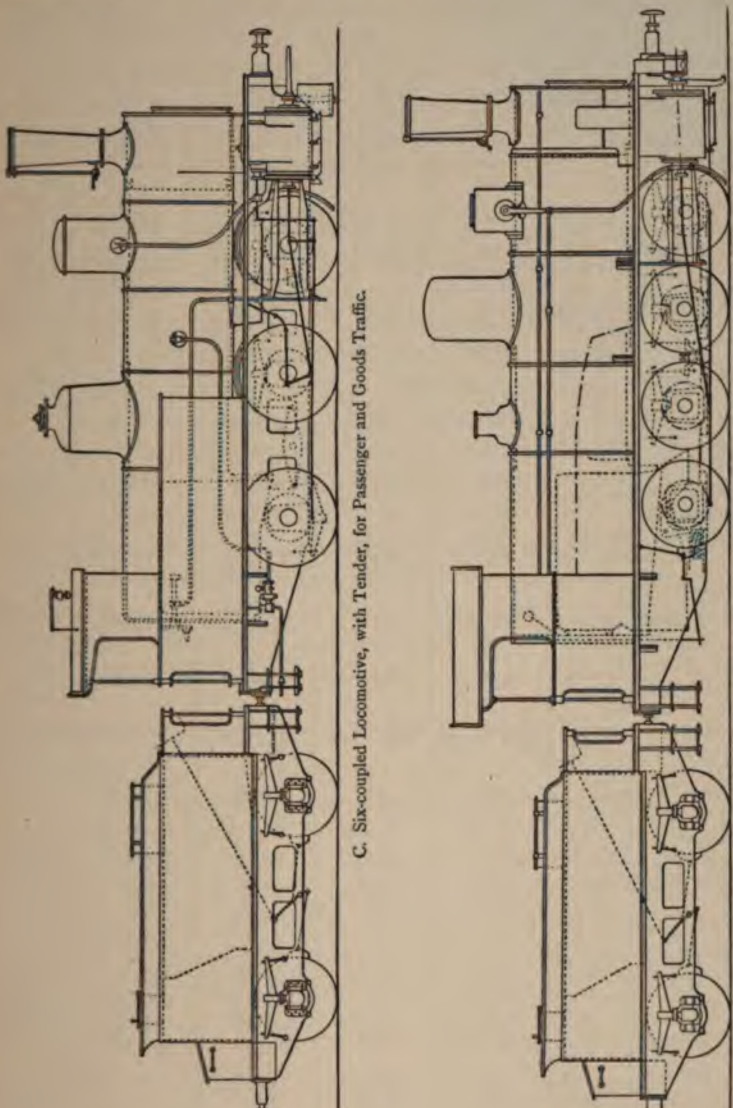


A′. Small Tank Locomotive, for Branch Traffic.

Figs. 851.—St. Gothard Railway: Types of Locomotives. Scale 1 100th.

and capable of drawing a train weight of 120 tons at a speed of 28 miles per hour, up an incline of 1 per cent, or 1 in 100. The weight of the trains, ordinary and express, is generally greater than that; and it would have been better to construct the engine with a tender.

The tender engine, C, is a powerful six-coupled engine, designed to draw goods trains on the easy lines, and any train on the mountain. It is capable of taking—



C. Six-coupled Locomotive, with Tender, for Passenger and Goods Traffic.

D. Eight-coupled Wheel Goods Locomotive, with Tender.

Figs. 852.—St. Gothard Railway: Types of Locomotives (continued). Scale 1/100th.

120 tons, at from 18 to 20 miles per hour, on an incline of 2½ per cent, or 1 in 40.
150 tons, at 10 miles per hour, on an incline of 1 in 40.
360 to 400 tons, at 11 miles per hour, on an incline of 1 in 100.

As this engine weighs 14 tons per axle, it represents nearly the maximum

Table No. 177.—Types of Locomotives, St. Gothard Railway.

Designation of Engine......	Tank Engines.			Tender Engines.	
	A′	B′	C′	C	D
Cylinders, diameter...inches	8.66	16.1	18.9	18.9	20.5
Do. stroke...... "	13.8	24.1	25.2	25.2	24.0
Driving wheels, diameter "	39.4	62.4	63.0	63.0	45.1
Carrying wheels, do. "	—	33.6	33.5	—	—
Wheel-base, coupled wheels ....ft. in.	8 2¾	6 10½	11 2	12 ¾	12 9½
Wheel-base, bogie ..... "	—	5 11	—	—	—
Do. total...... "	8 2¾	20 8	19 2	12 ¾	12 9½
Weight of engine, empty, tons	11.60	33.00	41.40	36.10	44.70
Do. in working order, with store of fuel and water...... "	14.68	44.20	57.00	—	51.70
Weight of engine, in working order, without store of fuel and water "	12.66	36.82	47.50	—	
Weight, driving, for adhesion, maximum...... "	14.90	27.60	43.00	43.92	51.70
Do. do. minimum... "	12.90	21.60	34.00	41.46	51.70
Frame plates, thickness, inch	.40	1.30	1.18	1.18	1.38
Do. length...ft. ins.	17 8	29 2	29 4½	26 9	28 2
Extreme length over buffers (including tenders)................. "	21 8	33 1	33 11½	48 0	48 9
Driving and coupled axles, diameter........ ins.	4.72	6.50	7.48	7.48	7.87
Driving and coupled axle journals, diameter and length..... "	4.72 × 7.09	6.69 × 9.45	7.87 × 9.45	7.87 × 9.45	7.87 × 9.45
Barrel of boiler, diam... "	31.66	48.42	57.09	57.09	60.44
Total length of boiler, including smoke-box ft. in.	12 7½	15 6¾	15 10¾	15 10¾	24 5
Fire-grate, area..........sq. ft.	4.10	14.85	19.56	19.56	23.11
Number of flue-tubes...tubes	69	150	207	207	225
Diameter..................ins.	1.77	2.01	1.97	1.97	1.97
Length between plates..ft. in.	8 2	13 2	12 9½	12 9½	13 9½
Heating surface—					
Fire-box..................sq. ft.	26.90	78.50	94.00	94.00	102.10
Tubes..................... "	262.30	1035.00	1363.40	1363.40	1596.30
Total .... "	289.20	1113.50	1457.40	1457.40	1698.40
Ratio to grate-area ... "	70.5 to 1	75 to 1	74.5 to 1	74.5 to 1	73.5 to 1
Capacity for water ....gals.	355	1194	1555	—	—
Do. coal.........tons	.42	2.00	2.50	—	—
TENDER (4-wheeled).					
Capacity for water.......gals.	—	—	—	1888	1822
Do. coal.........tons	—	—	—	4.50	4.80
Diameter of wheels......ft. in.	—	—	—	3 7¾	3 8
Weight empty.............tons	—	—	—	9.62	9.62
Do. loaded............ "	—	—	—	23.00	23.00

of power of an engine on three axles. The boiler is large, and holds 5 tons of water,—a good regulator of pressure.

The tank engine, C′, was designed for passenger traffic on the mountain, and goods traffic on the easy lines. It is substantially the same as the preceding, C, with the addition of a leading pair of carrying wheels, radiating on the Bissel system, like the American pony-truck, and tanks and coal-boxes. This class of engine has proved inconvenient for inspection and working, the tanks being much in the way and the room on the foot-plate too limited for properly attending to the fire without great labour. This class is being abandoned.

The goods engine, type D, is an eight-coupled wheel engine, for working goods trains on the mountain. It can draw from 175 to 180 tons up an incline of 2½ per cent, or 1 in 40; so that the train of 360 tons taken on the easy lines by one engine, C, is taken on the mountain by two engines, D.

The small tank engine, A′, is designed for working branches.

The locomotive stock thus noticed has been designed specially with a view to the passage over a line laid out with a great number of curves of 15 chains radius (300 metres) without difficulty. This object has been successfully attained: by the bogie of the engine B′, and the restricted wheel-bases of the engines C and D.

Experience has shown that the tank engines are not suited for heavy trains on great lines; and that it is better to utilize the disposable margin of engine load in augmenting the power of the engine, and providing a tender for fuel and water. But for short lines, especially mountain lines, the tank engine is advantageous.

CHAPTER LXI.—TRACTIVE POWER OF LOCOMOTIVES AND RESISTANCE OF TRAINS.

Two cylinders of equal diameters are universally employed in locomotives, coupled to one axle, except in compound-cylinder locomotives, now coming to the front. For cylinders of equal diameter the pressure or tractive force as at the rails, equivalent to the effective mean pressure, is given by the following formula, first, it is believed, propounded by Pambour:—

$$T = \frac{d^2 L p}{D} \quad \text{(1)}$$

Reversely, the effective mean pressure on the pistons, equivalent to a given tractive force as at the rails, is expressed by the formula:—

$$p = \frac{DT}{d^2 L} \quad \text{(2)}$$

d = the diameter of the cylinders, in inches.
L = the length of the stroke, in inches.
D = the diameter of the driving wheels, in inches.
p = the effective mean pressure on the piston, in pounds per square inch.
T = the equivalent tractive force, as at the rails, in pounds.

RULE 1.—*To find the tractive force.* Multiply the square of the diameter of the pistons, in inches, by the length of the stroke, in inches, and by the effective mean pressure on the pistons, in pounds per square inch; and divide the product by the diameter of the driving wheels, in inches. The quotient is the equivalent force, as tractive force, at the rails in pounds.

RULE 2.—*To find the required effective mean pressure in the cylinders.* Multiply the diameter of the driving wheels, in inches, by the total equivalent tractive force, as at the rails, in pounds; and divide the product by the square of the diameter of the cylinders, in inches, and by the length of the stroke in inches. The quotient is the required effective mean pressure in pounds per square inch.

It is understood, of course, that so much of the force developed in the cylinders, as is necessary to overcome the resistance of the machinery of the engine, is intercepted and consumed; and that only the balance of the force is available for tractional action at the rails, and there exerted. But, for the sake of reducing, for purposes of estimation, all the resistances of the engine, as well as those of the train, to one standard for measurement, the whole of the net or effective steam-pressure in the cylinders, measurable by the indicator, is reduced to an equivalent tractional force as at the rails.

The effective mean pressures in the cylinders of locomotives, deduced by the author from indicator diagrams (Plate I. vol. i. page 456) taken by Sir Daniel Gooch from the "Great Britain" locomotive on the Great Western Railway, are given in the table No. 178,[1] for various periods of admission, of from 10 per cent to 75 per cent of the stroke, for maximum pressures of steam of from 70 lbs. to 100 lbs. per square inch above the atmosphere in the cylinders. The values are approximately correct for higher pressures up to 140 lbs. per square inch. The rule by means of which the values in the table were calculated is as follows:—

RULE 3.—*To find the effective mean pressure in the cylinder, the maximum pressure being given, and the period of admission.* Find the square root of the period of admission, expressed in per cent of the stroke; multiply it by 13.5, and subtract 28 from the product. The remainder is the effective mean pressure in per cent of the maximum pressure of the steam admitted.

The formula is as follows:—

$$P = 13.5\sqrt{a} - 28. \qquad (3)$$

P = effective mean pressure, in per cent of the maximum pressure of admission above the atmosphere.

a = period of admission in per cent of the stroke.

The proportion of the adhesion weight, or driving weight of the engine, which measures the force of adhesion available as tractive force, is very variable:—from one-fifth in dry weather, according to the author's experiments on the adhesion of iron-tyred wheels upon iron rails, to one-ninth in damp weather, when the rails may be slippery. To keep within the limits of one-ninth in proportioning locomotives to their work, would implicitly

[1] Copied from [illegible] 1855; page 116.

Table No. 178.—EFFECTIVE MEAN PRESSURES IN THE CYLINDERS OF LOCOMOTIVES.

Stroke = 100. Maximum effective pressure during admission = 100.

Period of Admission.	Effective Mean Pressure.	Period of Admission in Fractions of the Stroke.	Effective Mean Pressure, in Fractions.
per cent.	per cent.		
10	15	1-10th	1-7th fully.
12.5	20	1-8th	1-5th.
15	24	......	......
17.5	28	1-6th	1-4th.
20	32	1-5th	1-3d.
25	40	1-4th	1-2.5th.
30	46	......	......
35	52	1-3d	1-2d.
40	57	......	......
45	62	......	......
50	67	1-2d	2-3ds.
55	72	......	......
60	77	......	......
65	81	2-3ds	4-5ths.
70	85	......	......
75	89	3-4ths	9-10ths.

ensure the working of the engine in all states of weather; but a larger fraction may wisely be assumed for the purposes of general estimates, particularly as the aid of dry sand dropped on the rails may be invoked, when needful, for the augmentation of adhesive force. A fraction of from one-sixth to one-seventh may be adopted.

The fraction one-sixth gives an adhesion of (2240÷6=) 373 pounds per ton of weight. The fraction $^1/_{6.4}$ would give an adhesion of 350 pounds per ton—an easily-remembered number. Adopting this unit, the adhesions for different weights are as follows:—

Weight.	Adhesion, or Available Tractive Force, as at the Rails.
tons.	pounds.
10	3,500
20	7,000
30	10,500
40	14,000
50	17,500

The resistances of locomotives and trains are of two kinds:—the frictional resistance to traction on a line of rails, and the resistance of gravitation on inclined planes on railways when they are ascended by the train. With respect to the resistance to traction, the author constructed a simple formula, deduced from the results of Sir Daniel Gooch's experiments, for the resistance on a level line of rails of the engine and tender with passenger trains:[1]—

[1] The resistance of engines and trains on railways is thoroughly investigated in *Railway Machinery*, 1855; page 291, &c.

$$R = 8 + \frac{v^2}{171} \quad \text{.................................} \quad (4)$$

v = the speed in miles per hour.
R = the total resistance of the engine, tender, and train in pounds per ton.

RULE 4.—*To find the total resistance of the engine, tender, and train, at a given speed.* Square the speed in miles per hour, divide it by 171, and add 8 to the quotient. The sum is the total equivalent resistance as reduced to the rails in pounds per ton of the gross weight.

Conditions under which the formula applies:—

1. The permanent way in good order.
2. The engine, tender, and train in good order; the train consisting of six-wheeled carriages lubricated with grease.
3. A straight and level line of rails.
4. Fair weather, and dry and clean rails.
5. An average side wind, of average force, varying (during the experiments) from *slight* to *very strong*.

The resistance may be considerably augmented by unfavourable circumstances. By a combination of frequent curves, under one mile radius, with strong side and head winds, the resistance to traction may be raised 50 per cent. But the above formula (4) is commonly employed by engineers in calculations for estimating the resistance of trains and the power of locomotives. The annexed table, No. 179, gives the resistances per ton of engine, tender, and train, for various speeds and various gradients, based on formula (4), extracted from *Railway Machinery*, page 310.

It is worthy of special observation that the resistance of trains—adopting as a standard for comparison the current practice of trains in England—may be considerably modified by the way in which the train is placed on its wheels; for instance, by placing the train on bogie-frames and wheels, and by lubrication of the train with oil instead of grease. The results of observations made by the author on the resistance of goods waggons,[1] show an extraordinary range of resistance, varying from 7½ lbs. per ton of the train alone, and 13 lbs. including the engine, to 29 lbs. per ton of engine, tender, and train, at speeds under 30 miles per hour. Such extreme diversity was no doubt due to the comparative freedom and state of repair of the waggons, and of the way, the state of the lubrication, and the curves on the line.

Again, in the working of two coal trains consisting of waggons having inside bearings, the following diverse results were obtained for the gross resistance of engine, tender, and train:—

At 11 miles per hour .... 27 lbs. per ton.
" 13 " " .... 18 lbs. "

The second train had only two- ... istance of the first; and the advantage was no doubt ... the journals in

[1] See ...

Table No. 179.—Resistance of Passenger Engines and Trains on Railways.

Ascending Gradients.	Conditions:— A good, sound road. A straight road. An average side wind. Engine, tender, and train in good working order, with grease lubrication.						
	Speed in Miles per Hour.						
	10	20	30	40	50	60	70
	Total Resistance in Pounds per Ton. Constant, 8 lbs.						
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Level	8.6	10.3	13.2	17.3	22.6	29	36.6
1 in 40	64	66	69	73	79	85	93
1 in 60	46	48	50	55	60	66	74
1 in 80	36	38	41	45	51	57	65
1 in 100	31	33	36	40	45	51	59
1 in 150	24	26	28	32	38	44	51
1 in 200	20	22	25	29	34	40	48
1 in 250	18	20	22	26	32	38	46
1 in 300	16	18	21	25	30	36	44
1 in 500	13	15	18	22	27	33	41
1 in 800	11	13	16	20	25	32	39
1 in 1000	11	12	15	19	25	30	39
Level	8.6	10.3	13.2	17.3	22.6	29	36.6

Note.—Fifty per cent of the resistance as on a level may be added for cases of frequent curves, of or under one mile in radius, in connection with strong side and head winds.

the bearings, in the second case, by which the wheels were free to adapt themselves without effort to the rails. In the first case, by the want of such play, the wheels were prevented from so adjusting themselves laterally without at the same time swaying the superincumbent loads.

A great practical improvement of the day, at least as far as English rolling stock is concerned, is the substitution of radial axles and axle-boxes, or of bogie-frames and wheels, for the rigid wheel-bases of rolling stock. The practice in the United States of the universal employment of bogies under the engines, tenders, carriages, and waggons, is well worthy of analysis. By means of the bogie the tractive resistance of engines and trains is notably less than that of a parallel-axled stock.

A good means for judging of the comparative resistance of different forms of locomotives is to compare their performance on steep inclines, with which quick curves are usually associated. The results of the performance of a number of engines on inclines are given in table No. 180, abstracted partly from published statements, and partly from the observations of the author. The performances are reduced, for the sake of a direct comparison, to equivalent performances as on the steepest incline on the list, namely, 1 in 27, on the Mauritius Railway:—

Table No. 180.—PERFORMANCE OF LOCOMOTIVES ON STEEP INCLINES.

Railway or Locality.	Adhesion-weight.	Weight of Engine and Tender.	Weight of Train.	Gross Weight of Engine, Tender, and Train.	Ascending Gradient.	Equivalent Gross Weights or Loads, reduced for a Gradient of 1 in 27.
	tons.	tons.	tons.	tons.		tons.
1. Semmering Incline...	37.5	59	130	189	1 in 40	135 = 3.6 times the adhesion-weight.
2. Do. do. ...	46.5	66	175	241	1 in 40	173 = 3.4 { 3.72 do.
3. Do. do. ...	37	56.4	100	156.4	1 in 40	112 = 3.02 do.
4. Great North of Scotland, bogie and tender	17.5	43	189	232	1 in 75	103 = 6.2 { 6.0 do.
5. Do. do. do. ...	17.5	43	144	187	1 in 50	112 = 6.4 do.
6. Great North of Scotland, tank engine	25	25	209	234	1 in 59	123 = 5.2 { 5.0 do.
7. Do. do. do. ...	25	25	231	256	1 in 59	135 = 5.4 do.
8. Giovi Incline, two tank engines coupled together...	55	55	100	155	1 in 29	145 = 2.6 do.
9. Mauritius Railway...	48	48	100	148	1 in 27	148 = 3.0 do.
10. Santander Railway	36	45	200	245	1 in 50	147 = 4.0 do.

It appears that the Semmering engines, having coupled parallel axles, take three times their adhesion-weight. The Giovi engines, being two tank engines coupled together, take an equivalent little more than two and a half times their adhesion-weight. The Mauritius engines having coupled parallel axles, take three times their adhesion-weight. The Santander coupled engines with a leading bogie, take an equivalent of four times their adhesion-weight. The four-coupled-wheel tank engines of the Great North of Scotland Railway take up more than five times their adhesion-weight; and the four-coupled goods engines, with a leading bogie, on the same line, take up an equivalent of more than six times their adhesion-weight. A comparison of these equivalent performances clearly shows that the bogie engine is more efficient for available tractive power than the ordinary multi-coupled engine without bogies. The comparatively low performance of the Giovi engines is a consequence of the ordinary but defective mode of coupling two engines together, namely, a short central coupling with a great overhang from the wheel-base, which induces considerable leverage to bind the engines hard against the inner rail on curves. The advantage of the bogie is very directly shown by comparing the two Great North engines, of which the four-coupled-wheel tank engines weigh each 25 tons, all adhesion-weight; and they move an equivalent gross load, including their own weight, averaging 130 tons; whereas the bogie engine, with only 17½ tons adhesion-weight, moves an equivalent gross load of 110 tons. That is, with about two-thirds of adhesion-weight, the bogie engines take six-sevenths of the gross load taken by the tank engines.

Locomotives on two independent trucks or bogies are constructed for lines of steep gradients and quick curve International Exhibition

of 1862, designs of an "articulated tank locomotive of great power" were exhibited by Messrs. J. J. & A. Meyer of Vienna. The engine was placed on twelve wheels, 3 feet 10 inches in diameter, all coupled, framed in two groups of six, with four 17¼-inch cylinders, of 19½ inches stroke, one pair to each group. Each group had a wheel-base of 8½ feet, and the centres of the bogies were 22 feet apart. The whole weight, estimated at 60 tons, was available for adhesion. This design was an important contribution towards a satisfactory solution of the problem of maximum-power goods engines. The Fairlie engine, to be subsequently noticed, is a development of the conception of Messrs. Meyer.

CHAPTER LXII.—FOUR-COUPLED EXPRESS PASSENGER LOCOMOTIVE, WITH TENDER.

DESIGNED BY MR. SAMUEL W. JOHNSON, FOR THE MIDLAND RAILWAY.

PLATE XV.

(Cylinders (inside), 18 inches by 26 inches; coupled wheels, 6 feet 9 inches. Gauge of way, 4 feet 8½ inches.)

The general arrangement and design of this locomotive are shown in Plate XV. and figs. 853 to 857. The cylinders are inside, and slightly inclined downwards, towards the driving axle, with four-coupled wheels and two axles behind, and a four-wheel bogie at the front: all having inside bearings. The driving wheels with their axle—the crank axle—are placed in front of the fire-box; and the back coupled-wheels with their axle —a straight axle—behind the fire-box. The gauge of the rails is 4 feet 8½ inches.

Weight of Locomotive and Tender.

	Empty.				In Full Working Order.		
	tons.	cwts.	qrs.		tons.	cwts.	qrs.
Leading (bogie) wheels,.......	12	18	3	....	14	6	0
Driving wheels,.................	13	18	2	....	14	11	2
Trailing wheels,.................	11	13	3	....	12	16	0
Total weight of engine,...	38	11	0	....	41	13	2
Weight of tender,..............	18	17	0	....	33	19	0
Engine and tender, ...	57	8	0	....	75	12	2

This engine, with others like it, may be taken as a development of the ordinary six-wheel, four-coupled inside-cylinder passenger engine, into an eight-wheel bogie-engine. The driving axle has been placed as near as possible to the firebox-shell, which is 21 inches from the centre of the axle: just sufficient to clear the cranks and the connecting-rods. The trailing axle also is placed as near as is practicable to the fire-box: it is 10 inches behind it, measuring from the centre-line of the axle. By

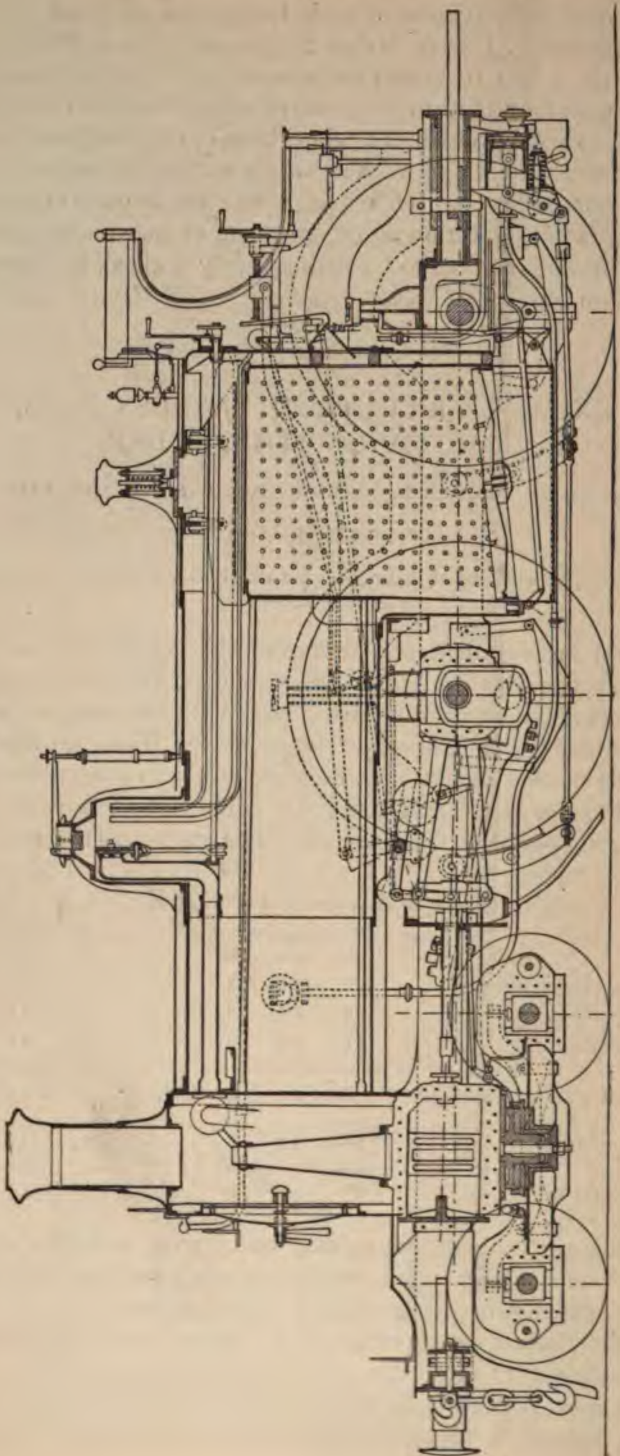
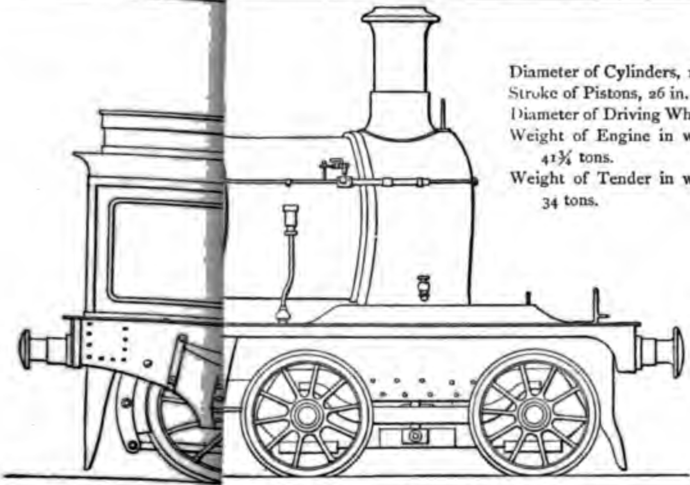


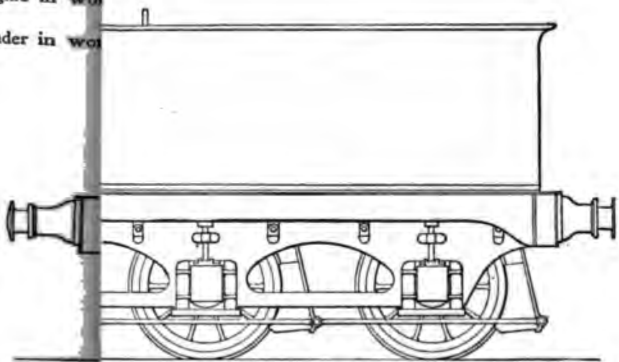
Fig. 853.—Midland Railway: Four-coupled Express Passenger Locomotive, designed by Mr. Samuel W. Johnson. Sectional Elevation. Scale 1/50th.



Diameter of Cylinders, 18 in.
Stroke of Pistons, 26 in.
Diameter of Driving Wheels, 6 ft. 9 in.
Weight of Engine in working order, 41¾ tons.
Weight of Tender in working order, 34 tons.

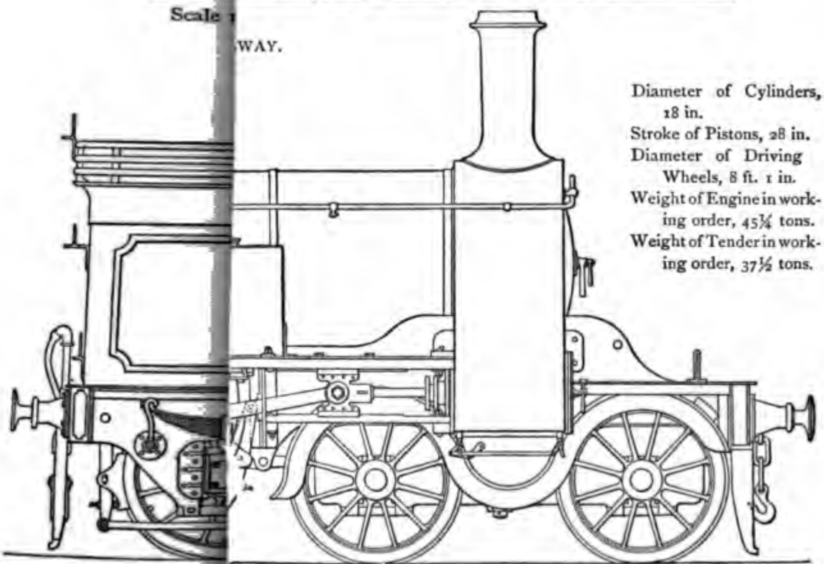
Scale SON, FOR THE MIDLAND RAILWAY.

Diameter of Cylinders, 17
Stroke of Pistons, 26 in.
Diameter of Driving Whe
Weight of Engine in wo
39⅛ tons.
Weight of Tender in wo
27 tons.



Scale 1

WAY.



Diameter of Cylinders, 18 in.
Stroke of Pistons, 28 in.
Diameter of Driving Wheels, 8 ft. 1 in.
Weight of Engine in working order, 45¼ tons.
Weight of Tender in working order, 37½ tons.

Scale 1–56th NG, *FOR THE* GREAT NORTHERN RAILWAY.

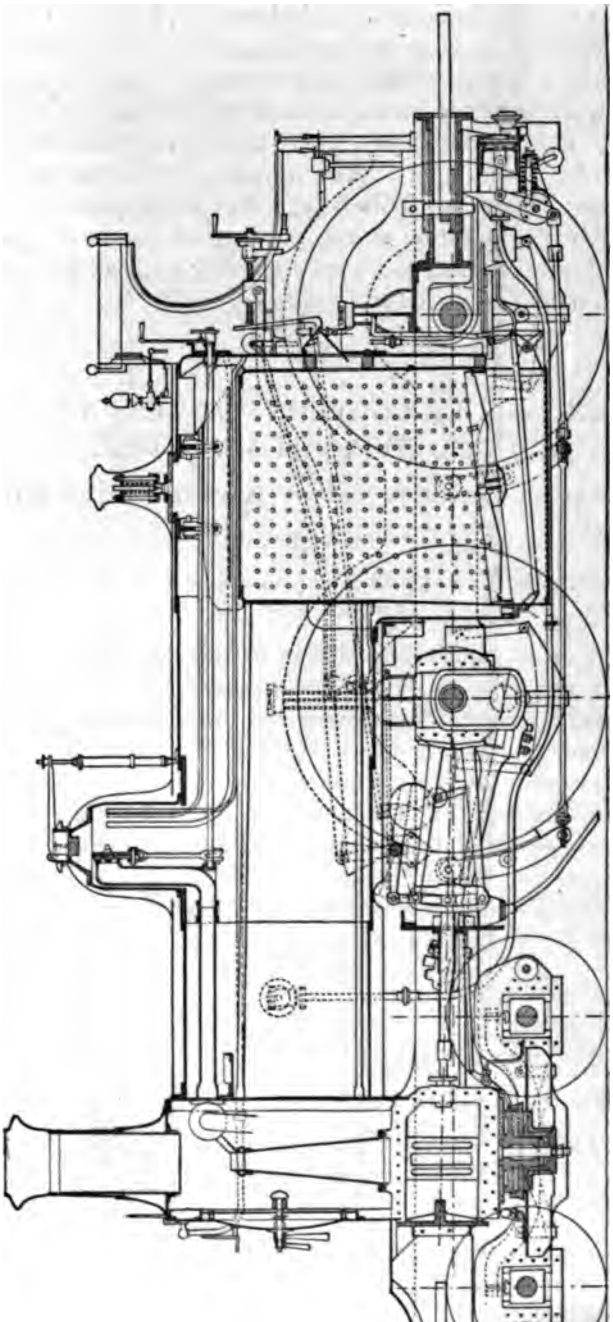
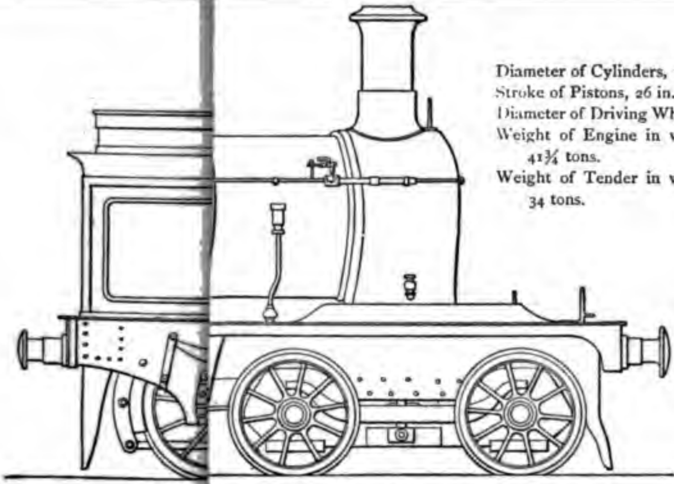


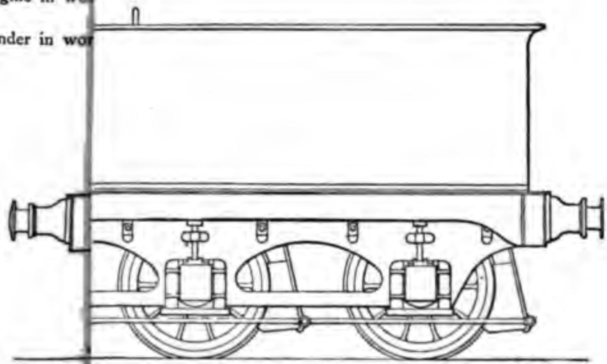
Fig. 853.—Midland Railway: Four-coupled Express Passenger Locomotive, designed by Mr. Samuel W. Johnson. Sectional Elevation. Scale 1/50th.



Diameter of Cylinders, 18 in.
Stroke of Pistons, 26 in.
Diameter of Driving Wheels, 6 ft. 9 in.
Weight of Engine in working order, 41¾ tons.
Weight of Tender in working order, 34 tons.

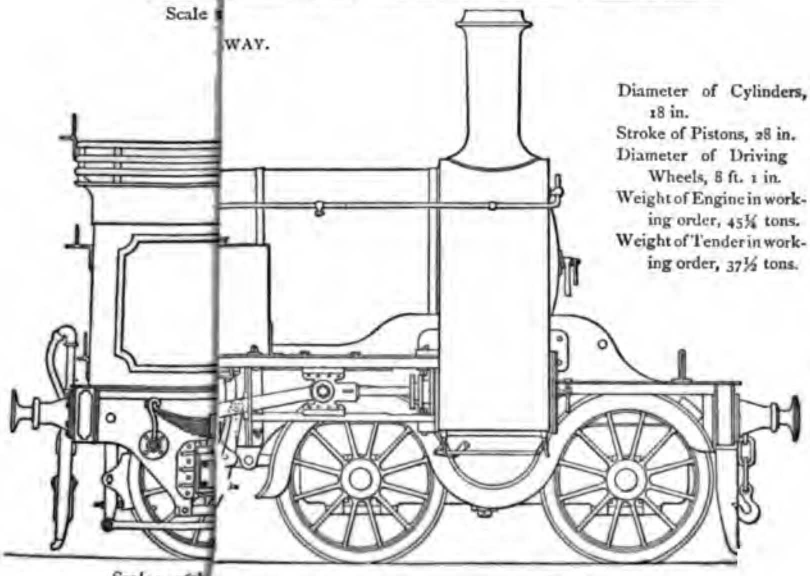
Scale SON, FOR THE MIDLAND RAILWAY.

Diameter of Cylinders, 17
Stroke of Pistons, 26 in.
Diameter of Driving Whe
Weight of Engine in wo
39½ tons.
Weight of Tender in wor
27 tons.



Scale

WAY.



Diameter of Cylinders, 18 in.
Stroke of Pistons, 28 in.
Diameter of Driving Wheels, 8 ft. 1 in.
Weight of Engine in working order, 45¾ tons.
Weight of Tender in working order, 37½ tons.

Scale 1–56th G, FOR THE GREAT NORTHERN RAILWAY.

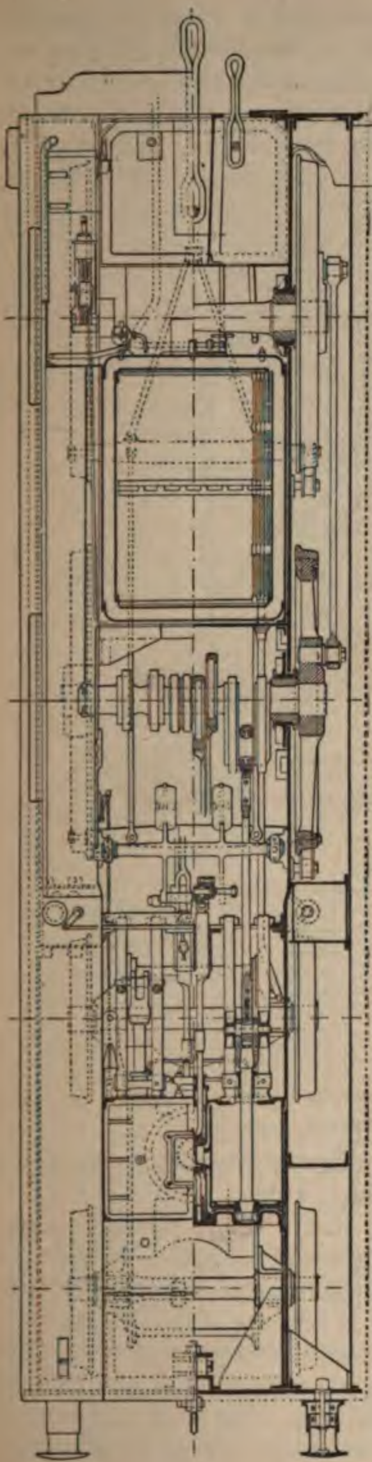


Fig. 854.—Midland Railway: Four-coupled Express Passenger Locomotive, designed by Mr. Samuel W. Johnson. Sectional Plan. Scale 1/50th.

such disposition, according to which the driving axle is placed as far back, and the driving and trailing axles are brought as near together, as is practicable, equal distribution of weight on the two axles is substantially effected, at the same time that provision is made for loading these axles with a suitable proportion of the gross weight of the engine. But, for securing this provision, the bogie is placed well in advance of the centre of gravity of the whole machine. For, the farther forward the bogie is placed, by the equation of moments, the less is the proportion of load that falls to the bogie, and the greater is the load incumbent on the other axles. The bogie is, in fact, placed directly under the cylinders and smokebox, its central pivot being 10 feet in advance of the driving axle, whilst this axle is 8½ feet in advance of the trailing axle; making a wheel-base of 18½ feet from the centre of the bogie to the trailing axle. The axles of the bogie are 6 feet apart between centres, and the total wheel-base upon which the engine is supported is equal to (3 feet + 10 feet + 8½ feet =) 21½ feet. The result of this stable distribution of axles and wheels is that the loads on the bogie and the driving axle are substantially equal; and that the weight at the trailing wheels is only a little less than that at the driving wheels. It is advantageous that some excess of weight should be on the driving wheels, which may thus to some extent be spared the stress of slipping into tautness with the coupling-rods and trailing wheels.

The position of the centre of gravity, horizontally, may be determined by the ordinary rule of the difference of moments,[1] or of the products of

[1] See *Railway Machinery*, page 189.

the leading and trailing weights by their respective distances from the driving axle. Thus, for the leading weight, the moment is (14.3 tons × 10 feet =) 143 foot-tons; for the trailing weight, the moment is (12.8 tons × 8.5 feet =) 108.8 foot-tons; the difference of these moments is 34.2 foot-tons, and the quotient of this difference by the total weight, 41.68 tons, is

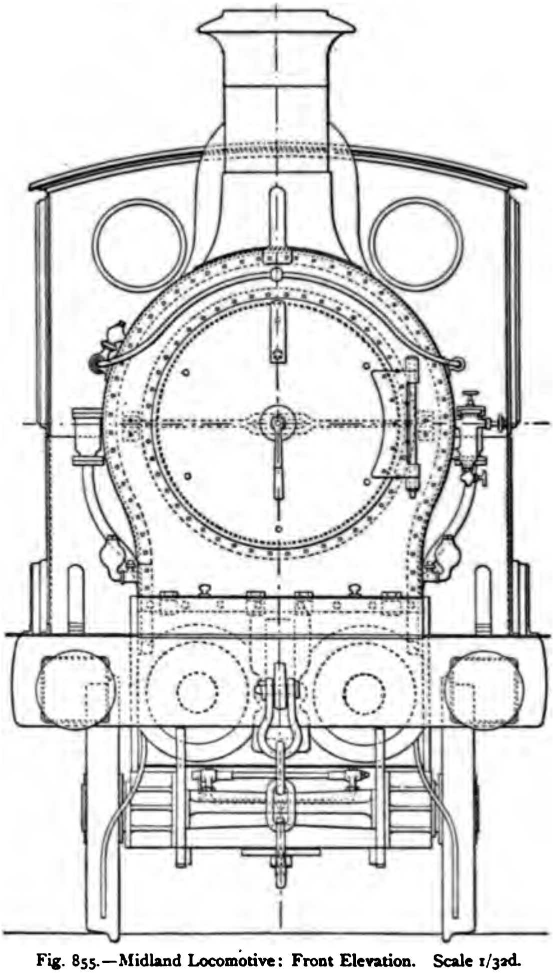


Fig. 855.—Midland Locomotive: Front Elevation. Scale 1/32d.

(34.2 ÷ 41.68 =) .82 foot, or 9⅞ inches, the distance horizontally by which the centre of gravity is in advance of the driving axle.

Supposing, for the sake of comparison, that a single pair of leading wheels be substituted for the bogie, the axle would be placed behind the smoke-box, at a distance of, say, 9 inches from it, measured to the centre-line. The leading axle would then be 8 feet in advance of the driving axle; and the wheel-base, fixed, would be (8 feet + 8½ feet =) 16½ feet. The distribution of weight, in working order, not allowing for the small modification introduced by the substitution, and su[illegible] that the central weight, or load at the crank axle, remains una[illegible]e as follows:—

	Tons.	Cwts.	Qrs.
Leading wheels	14	12	0
Driving do.	14	11	2
Trailing do.	12	10	0
	41	13	2

Showing that the leading weight would be augmented by 6 cwts. and the trailing weight would be diminished by 6 cwts., making a final preponderance of 2 tons 2 cwts. at the leading axle, over the weight at the trailing axle. The distribution of weight as it stands, with the bogie, is the better.[1]

In addition to the advantageous distribution of weight effected by the conveniently placed bogie, there is of course the practical advantage of a wheel-base partly flexible, of which the rigid portion is only 8½ feet in length, against 16½ feet with the single leading axle.

The gun-metal used in the construction of the engine, is composed of 5 parts of copper and 1 part of tin. White-metal is composed of 16 parts of tin, 2 parts of antimony, and 1½ parts of copper.

The class of engine herein noticed is mainly employed to work the

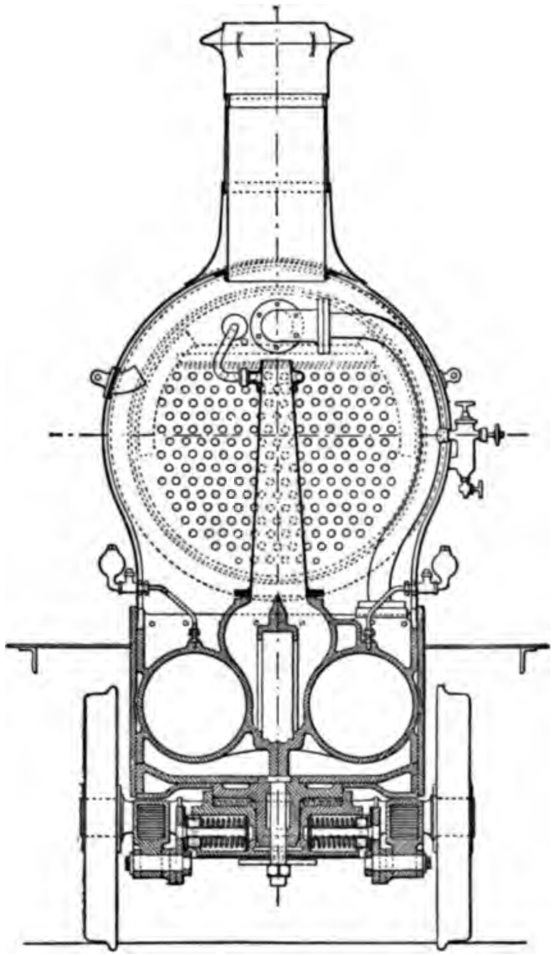


Fig. 856.—Midland Locomotive: Transverse Section of Smoke-box and Cylinders. Scale 1/32d.

[1] Let x = the weight at the leading axle;
y = do. do. trailing do.
The moment of the weight x relative to the centre of gravity is $x \times 7.18$ feet; that of the weight y is $y \times 9.32$ feet; and that of the central weight is (14.58 tons × .82 foot =) 11.95 foot-tons. The moments on one side of the centre of gravity balance those on the other; and, $7.18\,x = 9.32y + 11.95$; and, by reduction, $x = 1.3y + 1.66$.

But $x + y = 41.68$ tons − 14.58 tons central weight = 27.10 tons; and $x = 27.10 - y$. Equating the values of x,

$$1.3y + 1.66 = 27.10 - y;$$

and, by transposition and reduction, $y = 12.5$ tons, or 12 tons 10 cwts., and $x = (27.10 - 12.5 =)$ 14.6 tons, or 14 tons 12 cwts.: the values given in the text.

passenger traffic of the Leicester and Manchester, and the Settle and Carlisle sections of the Midland Railway. The normal work of the engine is to take 14 or 15 carriages—a load of 150 tons—up inclines of 1 in 100, at a speed of 35 miles per hour. The averaged time-bill speeds of the train are from 35 to 42 miles per hour, over inclines varying from 1 in 90 to 1 in 100 and 1 in 124, and so on; of from 8 miles to 15 miles in length;

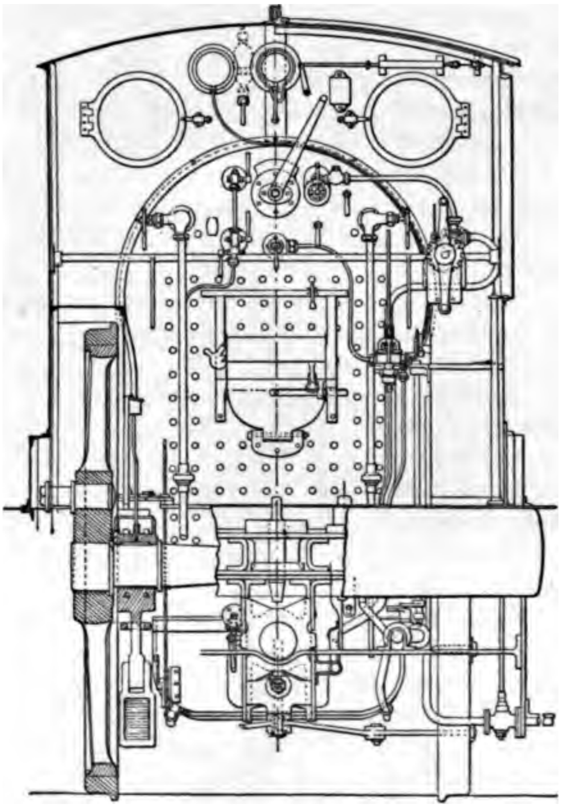


Fig. 857.—Midland Locomotive: End Elevation at the Fire-box End. Scale 1/32d.

and from 48 to 53 miles per hour over level lines and falling gradients. The usual rate of consumption of coal, ordinary Derbyshire, is from 26 to 30 pounds per mile. From 7 pounds to 8 pounds of water is evaporated per pound of coal.

The frame of the locomotive, which supports the boiler and the engine proper, is itself supported on the wheels and axles, with intermediate springs. The load is supported at five points:—the four bearings on the driving and trailing axles, and the central pivot bearing at the fore end, which is supported by the four wheels of the bogie. The placing of the front load on a central bearing, facilitates the yielding of the bogie to small inequalities of the way, whilst the mass of the engine is not affected by them. This fact, in conjunction with the swivelling play of the bogie to curves of the way, explain the efficiency and the popularity of this member.

The frame consists of two parallel longitudinal or side plates of Yorkshire iron, 1 inch thick, 28 feet 1 inch in length; and five transverse plates. The side plates have all bolt-holes and rivet-holes marked from one template, and drilled and rimered to the exact sizes. The side plates are 16¼ inches deep in the body, between the cylinders and the driving axle. At the cylinders, each plate is enlarged to 2 feet 7⅛ inches deep, to take not only the cylinder-flanges, but also the ends of the horizontal transverse frame-plate that receives the bogie-pivot, at the lower side; and the junction-laps of the smoke-box at the upper side. In advance of the cylinders, it is cut away to clear the forward bogie-wheels, and is reduced to 11¼ inches deep over these, and to 8½ inches further forward. But it is deepened to 15 5/16 inches at the front ends, when it is joined to the transverse buffer-plate. This overhung part of the frame-plate is stiffened by an extra ⅞-inch plate riveted to it. Between the driving and the trailing axle-guards, it is 18¾ inches deep, and at the end of the foot-plate 15 5/16 inches. Above the openings made for the axle-boxes, the frame-plates are 18 inches deep. The frame-plates, horizontally, are not straight from end to end; but are set with a small ogee bend just behind the motion-plate. They are 4 feet 1½ inches apart at the driving axle, and at the cylinders 3 feet 11¾ inches.

The back ends of the side frame-plates are 4 feet 4 inches from the centre of the trailing axle; and the fore ends are 5 feet 3 inches in advance of the bogie-pivot.

Of the transverse frame-plates, the end plates are each 1¼ inches thick. The front plate, or buffer beam, is 15 inches deep; the back one is 15 5/16 inches deep; and they are 7 feet 5 inches long. They are riveted to the longitudinal plates with 3½-inch angle-irons, except that the stiffening plates at the front ends of the longitudinals or side plates are flanged to take the end plates. The front plate is also bound to each side plate by a gusset-plate.

The next transverse plate, behind the cylinders, is the motion-plate, fig. 858, ⅞ inch thick, 27 inches deep. It is united to the longitudinal or side plates by a 3½-inch angle-iron, which is riveted to it on the back side along the top and down the ends, and by a piece of 3½-inch angle-iron at each end, on the front side of the plate. Thus, the motion-plate is fastened to each side plate with two angle-irons. These are each riveted to the side plates with five ⅞-inch rivets, countersunk at the outer side; and to the motion-plate with four ⅞-inch rivets. The motion-plate is slotted and drilled out for the guide-bars and connecting-rods, and valve-spindles.

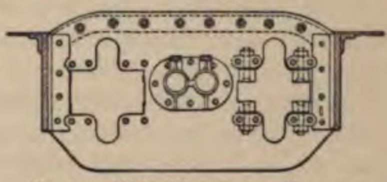


Fig. 858.—Midland Locomotive: Transverse Motion-plate. Scale 1/32d.

Then follows a ¾-inch transverse plate, in front of the fire-box, 10½ inches deep, joined to the side plates with two 3-inch angle-irons at each end. Lastly, of the intermediate plates, there is the draw-plate at some

distance behind the fire-box, ¾ inch thick, 15 5/16 inches deep. It forms with the back end-plate and the side plates, a draw chamber: these four members being united by two four-sided frames of 3½-inch angle-iron, one at the top and the other at the bottom. Two horizontal draw-plates are fitted into the rectangular space thus formed, and riveted to the two angle-iron frames, forming a chamber of 5½ inches clear depth, between the plates, in which the draw-link and two side links take their bearing on the 2¾-inch draw-pin and the two 1¾-inch side pins.

There is, in addition, the transverse horizontal plate, of Yorkshire iron, 1¼ inches thick, 28 inches wide between the side frame-plates, just below the cylinders; closely fitting to these, dished and flanged and planed to fit the side plates, to which they are fastened with five turned bolts and nuts at each side. It directly bears upon the bogie-pivot, which is bolted to it. Each end of the plate is fortified by an extra plate riveted to it, fitted to the side of the bogie-pivot, and finished so as just to clear the spring shackles of the bogie, which are beneath it.

Overhung lateral framing is provided for supporting the foot-plates. Two longitudinal angle-irons, 4½ inches deep, 2½ inches wide, and ⅝ inch thick, are fixed, one at each side, parallel to the main frame-plates, from end plate to end plate, to join which they are flanged at the ends. They are also each supported from the side plate by an intermediate bracket, at the cylinders, and a square cast-iron sand-box, at the motion-plate. They are also fortified by a ½-inch gusset-plate at each end, by which they are bound to the main frame-plate and the buffer-beam. The platform is of wrought iron, 5/16 inch thick over the front, two sides, and back of the framing; joined to the side plates with 3-inch angle-iron and ⅝-inch rivets at 5¾ inches of pitch. It measures 7 feet 7 inches of extreme width: overhanging each side frame-plate to the extent of 20⅝ inches. The cross-plate at the front, fitting the curved outline of the main frame-plates, is ⅜ inch thick; and the level plate at the front of the smoke-box is ¼ inch thick. The top of the frame under the platform is 4 feet 2 inches high above the level of the rails.

The steps at each side of the platform are welded to and dependent from the outer frame-bars, and the extreme width over the steps is 8 feet 2½ inches.

The bogie consists of a swivel-frame, on four wheels and two axles, with bearing springs, and horizontal springs for restoring the pivot to the centre-line of the engine, after being deflected on curves. The axles are at a distance of 6 feet from centre to centre, and they are equally distant from the central pivot. The frame is of the same quality of iron as the framing of the engine. It consists mainly of two side longitudinal plates 1⅜ inches thick, 13 inches deep at the centre, 7⅜ inches deep above the axle-boxes. They are 2 feet 7¾ inches apart, and are united by two transverse angle-irons, 6 inches by 6 inches by 1 inch thick, 10 inches apart, back to back; kneed at each end to join the side plates, for a length of 23 inches, and riveted to it. The angle-irons are slotted or planed at the ends to the exact

length, and the transverse parts are planed on both sides, horizontal and vertical. The extreme ends of the frame-plates beyond the axle-guards, are stayed together transversely with a 2-inch rod at each end, formed with a 6½-inch circular flange at each end, forged on. The flanges are riveted to the frame-plates, and the ends of the stay-bolt project through the plate, and are riveted over. A steel plate, to take the load, 6 inches wide, 1 inch thick, is riveted on the top of each angle-iron, at the centre. These plates are planed and scraped to give a good working surface. They are supplemented by two transverse ½-inch iron plates, inserted as stay-plates, and riveted to the angle-irons. The space between the angle-irons is occupied by a socket-casting, which is planed to slide between the angle-irons, and is permitted to have 2 inches of lateral play on each side of the central position. This casting is formed with a disc at the upper side, which is planed to rest on and work over the steel-bearing plates. These plates have oil grooves for lubrication by syphons. The disc is 25 inches in diameter, and is flanged at the circumference to a diameter of 22 inches inside. It is bored out vertically to a diameter of 7½ inches, to receive the pivot. The pivot is of cast iron, turned to 7½ inches in diameter, and 12½ inches high. It is formed with a disc at the upper part, 22 inches in diameter, which takes a bearing on a brass liner plate of the same diameter, 1½ inches thick, interposed between the upper and lower discs. The upper disc is bolted to the transverse wrought-iron plate, beneath the cylinders, already described as part of the engine frame, with six 1¼-inch bolts. It projects into the plate at the centre, and takes a bearing upon it by a circular flange with which it is bordered. A central 2½-inch safety-pin is let down through the pivot, and fitted with a washer 12 inches by 13 inches, 1¼ inches thick, loosely sustained by a nut and cotter.

The load is transmitted through two inverted springs, one next each frame-plate, which take the weight each on the central buckle. The ends of the springs are in links, pinned to the cradles at 3½-feet centres. The cradles, in which the springs are lodged, are of wrought iron. They are 5½ inches deep at the centre, 15/16 inch thick. Bosses are forged on for the spink-links and pins, and each end is forged solid and welded to the cradle-bars. The solid ends are drilled and tapped to receive an adjustable spring-pillar with a lock-nut, which takes its bearing direct on the axle-box. Each spring takes the load on the central buckle through a 2¾-inch pin, which has a bearing 4 inches long in the buckle, and is fastened to the frame-plate by a nut. In the event of the failure of this connection, the load comes direct on the upper face of the buckle, incurring a fall of only ⅛ inch.

The restoring springs for guiding the bogie into the right line, on leaving curves, are lodged horizontally between the transverse angle-irons. They each consist of a helical spring on Timmis' system, 4½ inches in diameter, and a Spencer cone-spring of prepared india-rubber, end to end, on one horizontal pin screwed into the side frame-plate. The springs are, when fixed, under a compressive stress of 30 cwts.

The axles of the bogie are 5¾ inches in diameter in the body, and 6½ inches at the wheel-seat. The journals are 5¾ inches in diameter, 9 inches long, and 3 feet 7 inches apart between centres. The collars of the journals are 7 inches in diameter.

The shell of the boiler, and all other iron used in its construction, are of Yorkshire iron. The barrel is of ½-inch plates, and is 10½ feet long "between plates"—that is to say, between the smoke-box and the firebox-shell. It is in three rings of plates, one plate for each ring, lapped telescopically, 4 feet 3 inches in diameter outside, at the end next the fire-box, and 4 feet 1 inch next the smoke-box. The firebox-shell is 5 feet 11 inches long outside, 4 feet ½ inch wide at the bottom, 5 feet 1½ inches deep below the centre-line of the barrel, at the front; sloped 7 inches upwards towards the back, and measuring 4 feet 6½ inches deep at the back. The upper part is semicircular to a radius of 2 feet 2 inches, overlapping the barrel—flush-topped, as it is called. There are one top-plate and two side-plates. The plates are ½ inch thick, except the smoke-box tube-plate, which is ¾ inch thick, and the front plate of the firebox-shell, which is 9/16 inch thick.

The transverse joints of the barrel and the firebox-shell are single-riveted, except at the seam joining these members, which is double-riveted. The longitudinal seams are butt-jointed, with outside and inside welts or butt-strips, double-riveted. The rivets are 13/16 inch in diameter, and pitched at 1⅞ inches apart—in a direct line for single-riveting, and zigzag for double-riveting. The two lines of rivets in double-riveting, taken parallel to the direction of the seam, are 1¼ inches apart, and the longitudinal pitch is 2¾ inches. The lap for single-riveting is 2½ inches; for double-riveting it is 3¾ inches. The welts or covering-pieces are twice as wide, or 7½ inches. The distance of the centres of the rivets from the edges of the plates and the welts is therefore 1¼ inches for both single and double riveting. The rivet-holes are very slightly countersunk at both sides; and the rivets are closed with cup-heads, 1¼ inches in diameter. The riveting is done by steam pressure. Rivets are made to completely fill the holes. The holes are so punched that when the plates are brought together, the smaller diameters of the holes meet. Holes which do not exactly meet are rimered out. Holes in angle-irons are marked off from the plates and drilled. The edges of all plates are planed. Any caulking required is done with a broad-faced fuller. Before being lagged the boiler is tested to a pressure of 200 lbs. per square inch with water, and afterwards to a pressure of 150 lbs. in steam. It receives a coat of boiled oil while hot.

The bursting strength of the double-riveted longitudinal joints is 4.4 times the working pressure. The ultimate strength of single-riveted joints is 56.6 per cent of that of the entire plate; that of double-riveted joints is 70.9 per cent.

The steam-dome is of ⅝-inch plate, 23 inches in diameter outside, 2 feet high, and welded at the seam. It is placed on the middle ring of plates of the barrel, to which it is joined with a flange worked on the lower

end, 3 inches wide. A butt-strip of ½-inch plate, 7½ inches wide, is welded to the flange at the front and the back, covering the seam of the barrel-plate, which is welded at the seam. The circular opening through the barrel-plate into the dome is 19¾ inches in diameter, and is strengthened by a ¾-inch "thickening plate" or flat ring, 4½ inches wide, applied at the inside, with two butt-strips welded to it, to match the dome-strips on the upper side. The three plates are riveted together by 42 rivets in single-riveting through the ring and circular flange, and double-riveting, as usual, for the butt-strips. The upper part of the dome falls in slightly, and is flanged inwards, leaving an opening 15 inches in diameter to form a seat for the cover carrying two safety-valves. The flanges of the dome and cover are faced to make a steam-tight joint.

The barrel is joined to the smoke-box tube-plate by an angle-iron ring, 4½ inches by 3½ inches, bored, faced and turned on the edges; ⅞ inch thick near the angle, tapering to ¾ inch at each edge; double-riveted to the barrel, single-riveted to the tube-plate. The back plate of the firebox-shell is flanged to a 2½-inch radius, and is single-riveted to the side and top plates.

A manhole, 14 inches by 12 inches, is cut in the top of the firebox-shell. It is strengthened by an imposed ring riveted to the plate, and closed with a cover-plate of 1⅛-inch iron, faced to make a steam-tight joint, with 15 1-inch stud-bolts and nuts.

The upper part of the back plate of the firebox-shell is stayed by four gusset or plate stays, ⅝ inch thick, riveted by angle-irons to the back and top plates. The upper part of the smoke-box tube-plate is stiffened by transverse angle-irons riveted to it.

The smoke-box is of BB Staffordshire iron plates. It is 2 feet 7 7/16 inches long, and is formed at the upper part to a radius of 2 feet 5¼ inches inside. The lower ends of the sides are riveted to the side frame-plates; and so, with the cylinders, complete the inclosure of the smoke-box. The covering plate is riveted to the tube-plate, which is flanged to receive it, lapped 2 inches, with ⅝-inch rivets, countersunk, at the outside, and filed smooth, at 3 inches of pitch. The front and side plates are united with 2½-inch angle-iron and countersunk rivets of the same diameter and pitch. The space on the top of the cylinders is filled in with broken fire-bricks and fire-clay.

The centre-line of the barrel of the boiler is 7 feet 2 inches above the level of the rails.

The chimney is of 3/16-inch plate, BB Staffordshire iron or Yorkshire iron. It has a liner 16⅛ inches in diameter inside, 2 feet 5½ inches long, which projects 3½ inches into the smoke-box. The base is of Yorkshire iron or of malleable cast iron. The chimney is topped by an ornamental casting of ¼-inch metal. The height of the chimney above the smoke-box is 3 feet 4 inches, and the total height above the rails is 13 feet.

The ash-pan, fitted to the bottom of the firebox-shell, is of 5/16-inch plates, joined with 2½-inch angle-iron, and ½-inch rivets at 4 inches pitch.

It has a horizontal floor, and is $10^5/_{16}$ inches deep outside at the front end, $15^{13}/_{16}$ inches at the back. The front is fitted with a movable door, worked from the foot-plate; also a small door at the back, for the purpose of clearing out the ash-pan.

The fire-box is of copper; the roof and sides being one plate. The stay-bolts and rivets are made from soft-rolled copper bars. Both plates and bars support a test of being doubled cold without making any sign of cracking. The fire-box is of ½-inch plates, except the tube-plate at the tubes, where it is $^{13}/_{16}$ inch thick. It is 5 feet $^9/_{16}$ inch long at the top inside, and 5 feet $2^{13}/_{16}$ inches at the bottom; the breadth at the bottom is 3 feet 4½ inches; the height at the front end is 5 feet 11½ inches, and at the back 5 feet 4½ inches. The height above the fire-grate at the middle is 5 feet 2½ inches. The water-spaces are 3 inches wide at the bottom; at the back the space widens upwards to 4 inches. The seams are single-riveted, with $^{13}/_{16}$-inch rivets at 1⅞ inches pitch, on 2½ inches of lap. The stay-bolts are ⅞ inch in diameter, screwed with eleven threads per inch; screwed tightly into the fire-box plates and shell plates, and riveted over at the ends. The thread of the screw is reduced at the portion of the stay between the plates. The tube-plate is also stayed by seven palm stays riveted to the lower half of the barrel. There are eight roof-stays of wrought iron, 2 inches thick, arranged in four pairs, of which the two middle pairs are 7 inches deep, and the outer pairs are 5½ inches deep. The stays of each pair are 2½ inches apart, and the lower surfaces of the stays are 1½ inches clear of the roof-plate. Each stay is fitted at the ends to take a bearing on the fire-box, and is fastened to the roof-plates with thirteen 1-inch screws, let through the roof-plate and screwed into the stay. Each pair of stays is slung from two T-irons riveted to the firebox-shell, with 1¼-inch pins.

The fire-box is fastened to the shell by a "foundation-ring," consisting of a 3-inch square bar of wrought iron, inserted between the plates, and fastened with a line of single-rivets.

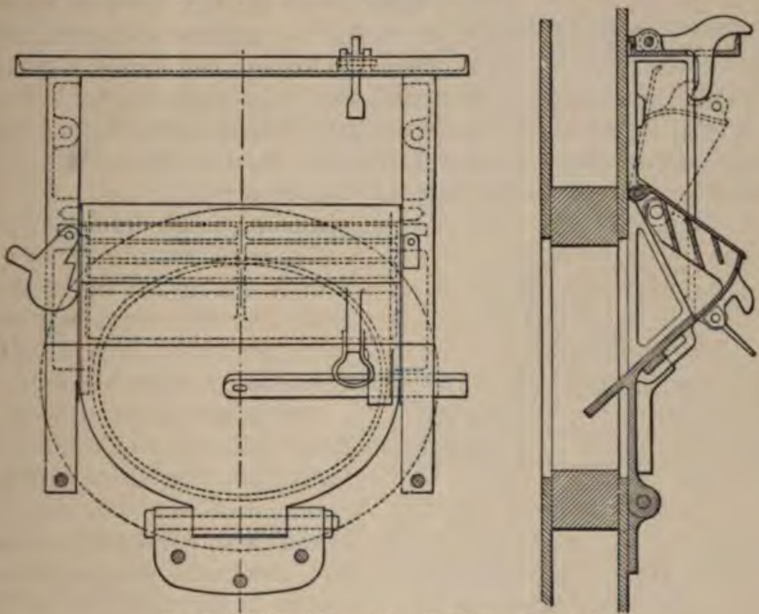
The fire-doorway is 15 inches wide and 12 inches high; and it is made with a wrought-iron ring 3 inches thick, inserted between the plates, fastened with a line of single-rivets.

The boiler is supported on the frame by two wrought-iron brackets, 2 feet 10½ inches long, riveted to the firebox-shell, which bear for their whole length on the side frame-plates. The brackets are secured by clips from the frame, but are free to slide horizontally according to the expansion and contraction of the boiler, which extends to $^5/_{16}$ inch longitudinally. The boiler is, on the contrary, riveted fast to the frame-plates at the cylinders, through the smoke-box, as already stated.

The fire-bars are of cast iron, in two lengths, 2 feet 6¼ inches long, supported on transverse wrought-iron bearers. They are ¾ inch thick at the upper edge, with $^9/_{16}$-inch air-spaces; 4¼ inches deep at the middle, tapered in thickness to ½ inch at the lower They are loose-fitted on the bearers and at the ends, to allow

A fire-brick arch, 4½ inches thick, 27 inches long, is constructed within the fire-box, with a rise of 2½ inches, abutting on the fire-box at each side. It starts from the tube-plate, just clear of the lowest row of flue-tubes, and is inclined upwards longitudinally, so that its lower side at the crown ranges with the top of the fire-doorway. In the doorway and projecting into the fire-box a baffle-plate of sheet iron, 29½ inches long, is placed, inclined downwards towards the arch, with a dip of 1½ inches below the range-line of the crown of the arch, leaving a free space of 11½ inches between the arch and the baffle-plate for the course of the draught.

The firehole-door, figs. 859, is of cast iron, in two parts, upper and lower, of which the upper part is hinged to side frames, just above the door-



Figs. 859.—Midland Locomotive: Fire-door. Scale 1/10th.

way, and opening upwards; and the lower is hinged just below the doorway, and opening downwards. When they are both closed the glare of the fire is completely intercepted. The upper part is formed with louvre blinds, through which air may enter from above, whilst the fire is invisible, the supply through the louvres being regulated by a covering flap hinged to the frame. The upper part of the door, carrying the flap with it, may be lifted and opened to any required extent, and kept in position by a catch; or it may be thrown right up out of the way, and kept up by another catch, whilst the lower part is let down, in order to open the doorway clear for the stoker.

Four gun-metal wash-out screw plugs, 1½ inches in diameter, are placed at the smoke-box end of the boiler, and eleven plugs on the firebox-shell. One wash-out doorway is cut through the foundation-ring at the front, 1½ inches by 2¾ inches, countersunk at the top and the bottom, to admit

the clearing rod at a low angle; closed by a wrought-iron block, 1¾ inches thick, and two 1-inch stud-bolts and nuts.

The flue-tubes are composed of 70 parts of copper, and 30 parts of Silesian spelter, and are solid-drawn. They are 205 in number, 10 feet 10 9/16 inches long between plates, 1¾ inches in diameter, except for a length of 3 inches at the smoke-box end, where they are 1⅞ inches in diameter. The thickness is No. 11 B.W.G. at the fire-box, and No. 13 at the smoke-box. They are arranged in fifteen horizontal rows, and are at 2 7/16 inches pitch at the fire-box tube-plate, making 11/16 inch of clearance between them. They are not horizontal, but they rise towards the smoke-box, insomuch that the upper row of tubes is 2 5/16 inches higher at the smoke-box than at the fire-box, and they are pitched at 2 9/16 inches. They are fixed into the fire-box tube-plate, fig. 860, with steel ferules 1⅛ inches long, fully 3/32 inch thick, 1 5/16 inches in diameter inside, at the front; tapered on the outside at the rate of 1 in 48, a tight driving fit; and 1 in 40 inside. At the smoke-box end the tubes project ¼ inch through the tube-plate, and are expanded.

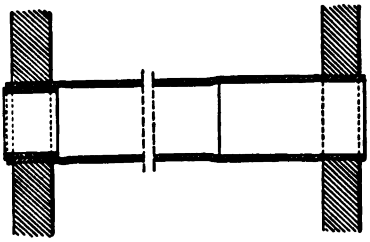
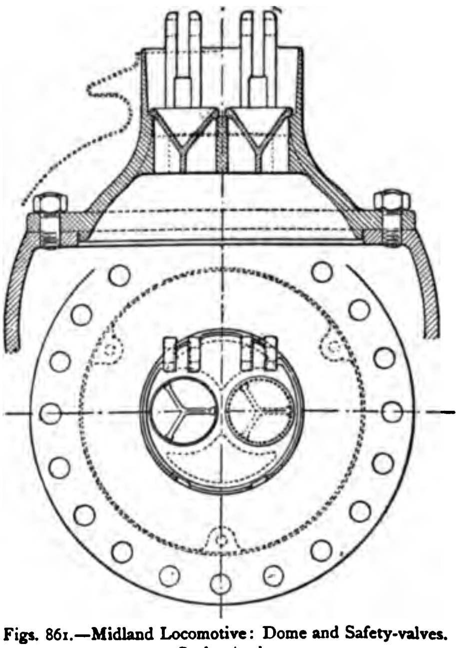


Fig. 860.—Midland Locomotive: Flue-tubes—Fastenings. Scale 1/4th.

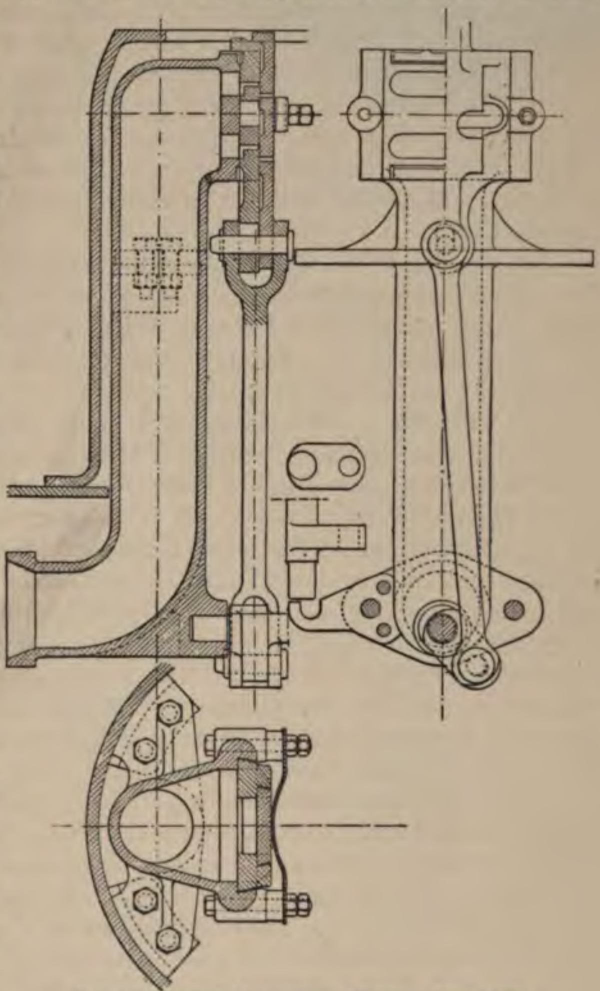


Figs. 861.—Midland Locomotive: Dome and Safety-valves. Scale 1/10th.

The dome-cover, figs. 861, is of gun-metal, ⅝ inch thick. It is fastened to the dome with twenty 1-inch stud-bolts and nuts. It is formed with seats 3 inches deep for two gun-metal safety-valves, 3 7/16 inches in diameter, the seating of which is only 1/16 inch wide. The valves are three-leaved, and are formed each with an inverted conical hollow on the upper side, in the bottom of which a pointed steel strut, ¾ inch in diameter, takes a bearing. The upper end of the strut takes the lever of a Salter's spring-balance, graduated to 200 lbs. per square inch, for 16-ounce balances. Each lever is of iron ⅝ inch thick, 1⅞ inches deep at the safety-valve. The fulcrum of each lever is a knife-edge bearing fixed at one side of the cover. The fulcrum end of each lever is case-hardened. The strut-bearing on each safety-valve is 3 inches from the fulcrum, and the length of the lever from the fulcrum to the spring-balance is 25⅜ inches, making a leverage of 8.46 to 1.

One 2-inch direct-action safety-valve is fixed on the manhole-cover. It is loaded with a helical spring of 7/16-inch round steel, 3 inches in diameter outside, to blow off at a pressure of 145 lbs. per square inch.

The steam-pipe inside the boiler is of copper, solid-drawn, 4 inches in diameter, No. 7 B.W.G. in thickness. It is enlarged to 5 inches in diameter at the smoke-box, and terminated with a brass flange. It is fixed to the tube-plate with a steel ferule, turned and made a tight fit. On the inner end of the pipe a brass cone is brazed. It is secured to the regulator casting by means of a wrought-iron clip and two bolts. At the outer end the steam-pipe is joined to a cast-iron elbow in the smoke-box, from which the steam is conducted by one 4-inch copper pipe, No. 7 B.W.G. in thickness, to a junction-pipe cast on one of the cylinders, and thence to the valve-chest.



Figs. 862.—Midland Locomotive: Regulator. Scale 1/10th.

The regulator, figs. 862, is a 4-inch cast-iron pipe, ½ inch thick, joined to the longitudinal copper pipe, as already described. It rises to the top of the dome, and it is supported by two flanges cast on it, which rest on and are bolted to angle-irons riveted to the inside of the dome. It terminates in a vertical face having two steam-ports 1¼ inches by 6 inches. A flat gun-metal valve, 1 inch thick, slides vertically on this face, and a flat cast-iron valve slides on the back of the brass valve. These valves are both moved by the same connecting link, but the pinhole for the brass valve is made oblong, in order that the cast-iron valve may be shifted while yet the brass valve remains at rest, and that steam may be admitted gradually into the pipe. For this object, when the lever is moved, steam is first admitted

through two small ports, ¼ inch by 3 inches each, in the outer valve, into and through two corresponding ports in the brass valve; and on a further movement of the lever, both valves are raised simultaneously, and then the large ports are opened for a full supply of steam. That the valves may lie closely to the pipe-face, the brass valve slides in dovetail guides on the pipe-face, and the cast-iron valve slides in dovetail guides on the back of the brass valve. The valves are further secured in place by a flat steel spring bearing on the back of the cast-iron valve. The valves are moved by a 2½-inch arm on the end of a 1½-inch rod, which takes a bearing in the lower end of the cast-iron pipe, and is extended through a stuffing-box on the back of the firebox-shell, where it is commanded by a handle of 18 inches radius. All levers, pins, and rods within the boiler are made to an easy fit.

The working pressure of steam in the boiler is 140 lbs. per square inch.

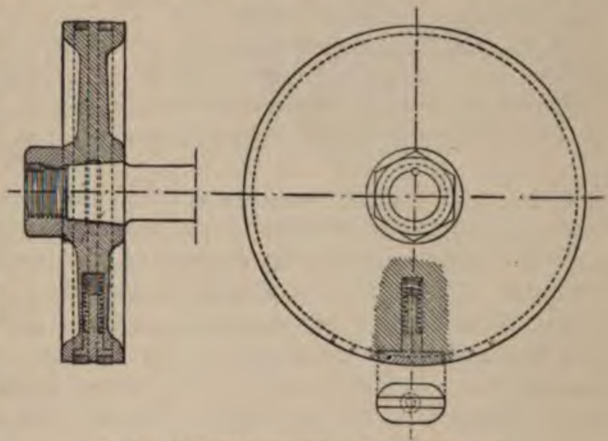
The normal water-level in the boiler, at half the height of the gauge-glass, is 4½ inches above the crown of the fire-box. The water-room in the boiler is about 114 cubic feet; the steam-room is about 38 cubic feet; together, 152 cubic feet of capacity.

The cylinders are of close-grained tough cold-blast iron, 18 inches in diameter, with a stroke of 26 inches. They are placed between the longitudinal frame-plates, at a distance apart of 2 feet 4 inches between the centre-lines. The slide-valves, one for each cylinder, are housed vertically between the cylinders, on the vertical valve-faces of which they slide, worked by the ordinary link-motion direct from the crank-axle. The spindles are only 3½ inches apart between centres. To make room for the cylinders the inner side of each longitudinal frame-plate is scooped out for about ¼ inch in depth. The steam-ports are 1⅜ inches long by 15½ inches broad, rounded at the sides; the exhaust-port is 3½ inches wide; the bridges or bars are 1 inch thick, and the working face or valve-face is 11¼ inches long. The sectional area of the steam-port is 20.6 square inches, or about $^1/_{12}$th of the area of the piston; the exhaust-port is $^1/_{4.7}$ part of the piston-area. The cylinders are bored out to a thickness of $^{15}/_{16}$ inch, and are slightly expanded or bell-mouthed at the ends. They are in two castings, united by 1⅝-inch flanges and twenty-nine 1-inch bolts and nuts at about 3 inches of pitch. The flanges at the lower side are double-bolted—the bolts being placed zigzag—for the sake of greater strength to take the front load. The metal of the valve-chest so formed up between the cylinders, is 1 inch thick, and the two valve-faces are 5¼ inches apart. The cylinders are each fastened to the side frame-plates with 1⅜-inch flanges, and twelve 1-inch bolts and nuts,—six in the upper flange and six in the lower. The end flanges are 1 inch thick, to take the covers, of which the front cover is ⅞ inch thick, and is fastened with twelve ⅞-inch stud-bolts and nuts; and the back cover is 1¼ inches thick, fastened with six 1-inch stud-bolts and nuts. The back flange of the cylinder is bolted to the smoke-box tube-plate with eight ¾-inch bolts and nuts. All joints and surfaces are planed, or turned and scraped to true surf[illegible]ake steam-tight joints.

The exhaust-pipe or blast-pipe is of cast iron, ⅜ inch thick. It is oval at the junction with the cylinders, 9½ inches by 11½ inches, and tapers upwards, finishing with a brass nozzle 4⅝ inches in diameter, terminating at a level of about 1½ inches above the tubes, or 13½ inches below the entrance of the chimney. The nozzle is cast with an annular channel round it, into which steam is admitted, and from which it escapes through sixteen small holes, to excite a draught in the chimney, when required for drawing up the fire, or keeping it up, and for the prevention of smoke when the blast is off the fire. Of the sixteen holes, eight are $^7/_{16}$ inch in diameter, alternating with eight ⅜-inch holes.

One of Roscoe's No. 3 lubricators is placed on the left-hand side of the smoke-box, and screwed into a boss on the side of the steam-pipe. One of Furness's lubricators is connected to each cylinder by a copper pipe and union, protected by a cast-iron shield. Water-cocks are provided for draining the valve-chest and each end of the cylinders, worked from the foot-plate. The piston-rod glands are made in halves, to admit of the piston-rods being drawn out. The under parts of the cylinders are lagged with wood.

The pistons, figs. 863, are of tough cast iron, made from cylinder-metal, each in one piece. They are 3¼ inches thick at the rim, but are reduced in the web between the nave and the rim to a thickness tapering from 1⅝ inches at the nave to 1⅜ inches at the rim. The diameter is $^1/_{32}$ inch less than that of the cylinder. There are two packing-rings of cast iron in each piston, ¾ inch wide and ⅜ inch thick. They are turned at the edges and the outside, ⅛ inch larger in diameter than the cylinder; then cut slantingly, and sprung into their places. A helical spring is inserted in the body of the piston, at the lower side, in order to relieve the gland of the weight of the piston.

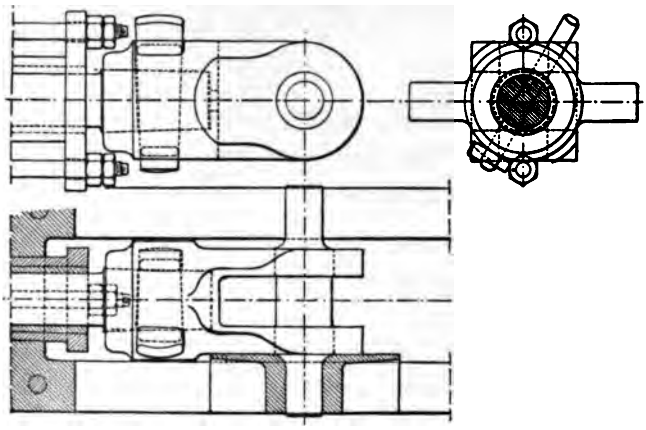


Figs. 863.—Midland Locomotive: Piston. Scale 1/10th.

The piston-rods are of mild crucible cast steel, well annealed, 2¾ inches in diameter, or $^1/_{6.65}$ part of the diameter of the cylinder. Each rod fits conically into the piston, tapering from 3½ inches to 2¾ inches. It is screwed and fastened by a nut 2 inches thick, which is secured by a ½-inch gagging screw. The other end of the piston-rod, figs. 863, is enlarged, in order to provide equivalent area for the reduction of section at the cotter-hole. The conical head is 5⅝ inches long, tapered from 3⅜ inches to

$3^1/_{16}$ inches in diameter, driven into the crosshead, and fixed there by a cotter 9¼ inches long, ⅞ inch thick, tapering in breadth from 2½ inches to 2 inches, rounded at the edges; secured by a small split cotter through the smaller end.

The crosshead, figs. 864, is of cast steel. It is 6¼ inches in diameter at the cotter-hole. The gudgeon or pin is of crucible cast-steel, of the same quality as the material of the piston-rod. It is 3 inches in diameter at the journal, and $3^1/_{16}$ inches in the jaws of the crosshead, which are $1\,^7/_{16}$ inches thick and 2⅝ inches apart. It is forced into the crosshead by hydraulic pressure. The slide-blocks are of chilled cast iron, 10 inches long, 3¼ inches wide, let on the projecting ends of the gudgeon, which are 2 inches in diameter.

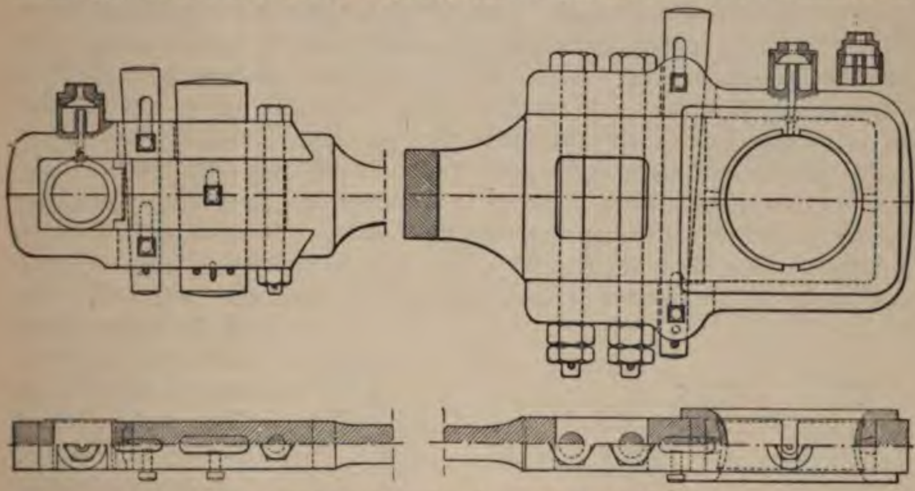


Figs. 864.—Midland Locomotive: Crosshead and Slides. Scale 1/10th.

There are two pairs of guide-bars, figs. 864, to each cylinder, 3 feet 10½ inches long. They are 2¾ inches wide, 2 inches thick, 3¼ inches apart vertically, and 6½ inches apart horizontally. They are fastened each pair by one $1^1/_{16}$-inch bolt and nut to the cylinder-cover at one end, and to blocks bolted to the motion-plate at the other end.

The connecting-rods, figs. 865, are of iron, forged in one length without welding. They are 6 feet 2¾ inches long, or 5¾ times the length of the crank. The body is rectangular in section, tapering from 4¾ inches by 1¾ inches thick at the crank-end, to 3 inches by 2 inches thick at the crosshead-end. The peculiarity is that the thickness tapers from the small end towards the large end. The bearings are 3 inches in diameter, 2⅝ inches long for the crosshead, and 7 inches by 3⅞ inches for the crank. The crosshead-end consists of a butt and a strap, of which the ends of the strap are wedge form, let into the butt, and are also secured by a 1-inch bolt and nut. The head of the bolt and the nut are each ⅞ inch thick, and the nut is secured by a round split-pin through the end of the bolt. The screw has 11 threads per inch. The butt is 3¾ inches wide, and the limbs of the strap are 2 inches thick, and reduced to 1⅜ inches thick at the brasses, where they are clear of the cotters. The brasses are of the same width as the butt, so allowing ⅜ inch of metal above and below; and there is ¾ inch of metal at each side. The brasses are square at each side, and without flanges. They are 2⅝ inches long to fit the journal, being ⅛ inch more in length than the thickness of the butt. making $^1/_{16}$ inch clearance

at each end. They are fastened by a steel bearing-piece, ½ inch thick, and a cotter 11¾ inches long, ⅝ inch thick, 2⅛ inches wide at the upper end, tapered to 1⅜ inches at the lower end, rounded at the edges. The taper is at the rate of about 1 in 16, and the incline is entirely on the side next the brass. The cotter is secured by two ⅝-inch steel set-screws through one side of the butt. Between this, the driving cotter, and the bolt already mentioned, a large permanent cotter is driven, to bring the strap home to the wedge joint. This cotter is 11 inches long, ⅞ inch thick, 3¾ inches wide at the top, tapered to 3½ inches at the bottom, and



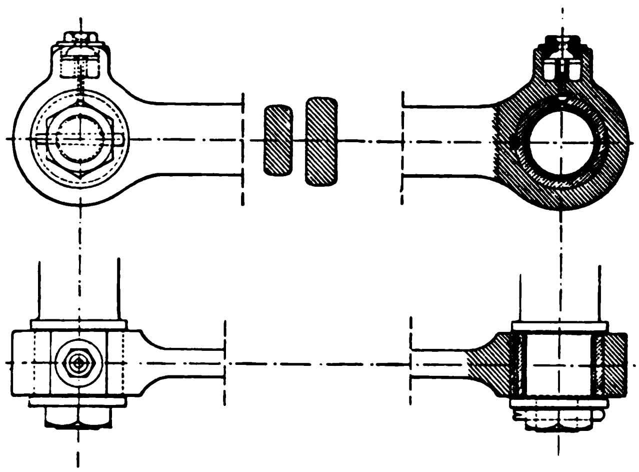
Figs. 865.—Midland Locomotive: Connecting-rods. Scale 1/10th.

is secured by one steel set-screw. The taper is at the rate of 1 in 44. The bolt and the cotters are of Lowmoor iron. An oil cup, forged solid on the strap, is bored out to 2 inches in diameter, 1⅞ inches deep, with a 5/16-inch wick-hole to the gudgeon, closed by a brass screw-cap.

The butt of the crank-end is a simple rectangular block, 8⅞ inches wide and 2¾ inches thick, slotted out in the middle to reduce deadweight. The strap is fastened to the butt with two 1¼-inch bolts and double-nuts, 11 threads per inch, each secured by a round split-pin. The heads of the bolts are 1 inch thick, the nuts 1¼ inch thick, and the jam-nuts ⅞ inch. These bolts and the bolt at the other end are drawn out of a solid bar, without any welding. The strap is 2¼ inches thick at the bolts, 1½ inches above and below the brasses, and rounded at the back to a maximum thickness of 1¾ inches. At the brasses the inside width of the strap is 8¾ inches, or ⅛ inch less than at the bolts. Thus the insertion and withdrawal of the brasses are facilitated. There is ⅞ inch of metal in the brasses at the top and the bottom. They are square at the front and the back, with 9/16-inch flanges to lap the butt and the strap. They are cottered up with a ¾-inch steel plate to take the pressure of the cotter, which is 18¼ inches long, ¾ inch thick, rounded at the edges, 2½ inches wide at the top, tapering to 1⅜ inches at the lower end, secured by two steel ⅝-inch set-

screws. The taper is at the rate of 1 in 16, and is entirely on the edge next the brass, the cotter being let into the steel bearing-plate. There is 1⅛ inches of metal at each side, fore and back of the brasses. They are lined with 5/16 inch of white metal. An oil cup, like that described for the crosshead-end, is forged solid on the strap.

The crank-axle is of Yorkshire iron, having two double cranks at right angles to each other; the right-hand crank leading, that is, 90° in advance of the left-hand crank when the engine goes forward. The trailing coupled-axle is of crucible steel, straight. Both axles are 7 inches in diameter in the body or middle portion; with 7½-inch journals, 7¼ inches long, 3 feet 11¾ inches apart from centre to centre, or 2¾ inches less than the distance apart of the longitudinal frame-plates between centres. Thus the centre-lines at each side are 1⅜ inches out of line. But they are only ½ inch out of line taking the frame-plates at the cylinders. The wheel-seats, outside the journals, are 8½ inches in diameter, 6⅝ inches long, with a collar ⅜ inch wide, 9 inches in diameter, let ¼ inch into the wheel, making together 6⅞ inches total length of seat for the wheel. This collar also forms the end of the journal. The body of the trailing axle is gradually increased in diameter from 7 inches at the middle to 9 inches at the ends, giving a ¾-inch collar to the inner end of the journal. The crank-pins of the crank-axle are 7 inches in diameter, 4 inches long, well rounded into the arms or webs of the crank. They are 2 feet 4 inches apart between centres. The crank-arms are 13 inches wide, 4¼ inches thick, and they are strengthened by straps or "hoops" of iron, 2½ inches by 1⅝ inches in section, shrunk upon them. The life of a crank-axle is from 197,351 miles to 220,000 miles run by the engine. The life is determined by inspection. The life of a straight coupled-axle is from 300,000 miles to 550,000 miles.



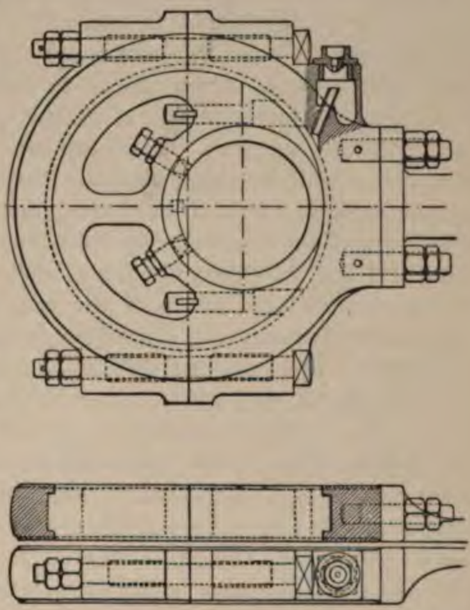
Figs. 866.—Midland Locomotive: Coupling-rods and Crank-pins. Scale 1/10th.

The coupling-rods, figs. 866, are of Vickers steel, of a tensile strength of 35 tons per square inch, with an elongation of 30 per cent. They are made with solid circular ends and brass bushes. They are 8½ feet long, and have bearings 3½ inches in diameter and 3½ inches long. The bushes are ⅝ inch thick, or 4¾ inches in diameter outside; 3⅜ inches long, or ⅛ inch shorter than the journal. They are lined with 3/16 inch of white

metal. The body of the rod is rectangular in section, 1⅜ inches thick, 3¼ inches deep, at the ends, swelled to a thickness of 1⅝ inches and a depth of 4¾ inches at the middle.

The valves are ordinary slide-valves worked direct from the driving-axle by link-motion. They are of gun-metal, 18½ inches by 10¼ inches on the face, and proportioned to give 1 inch of lap and 5/32 inch of lead in full gear. The travel in full gear is 3 13/16 inches, and the valve cuts off at a mean of 71¼ per cent. The body of the valve is of ½-inch metal; the face is 15/16 inch thick. The exhaust cavity is 2 inches deep. The valve is stiffened by two ribs or flanges across the cavity. The centre-line of the valve is 3 inches above that of the cylinders, at half length: affording facility for a free exhaust into the blast-pipe.

The valve-motion work is of best iron; the working and rubbing surfaces are case-hardened. The valve-spindle for each valve is 1¾ inches in diameter, welded to the buckle, which is lodged on the back of the valve. The buckle is 1 9/16 inches deep, 1⅛ inches thick at the ends, widening to 1¾ inches at the junction of the spindle. The valve is steadied by a back spindle, 1⅜ inches in diameter, sliding in a cast-iron guide at the front of the valve-chest. The four eccentrics, figs. 867, for working the link-motion for the two valves, are fixed on the crank-shaft between the cranks. They are 15¼ inches in diameter, 3 inches thick; turned down at the corners, ⅜ inch deep and ½ inch wide, leaving a width of 2 inches of the full diameter. The central opening is 7 inches in diameter, to fit the shaft; and the eccentricity is 3 inches, making 6 inches of throw. The eye or boss of the eccentric is 3¼ inches wide, projecting ⅛ inch at each side from the body of the eccentric. Each eccentric is in two pieces—the smaller piece of best iron, the larger of cylinder metal,—united on the axle by two 1-inch cotter bolts, with 1¼-inch cylindrical heads sunk into the smaller piece, and a steel cotter to each, 1⅛ inches by ¼ inch; also secured by two ⅞ inch steel set-screws, with a wrought-iron jam-nut to each. The eccentric straps are of cylinder-metal, 2 inches thick over the eccentric, and 3 inches wide. They are in halves, united by two 1⅛-inch bolts and double-nuts, 17 inches apart between centres, and only 5/16 inch clear of the eccentric at each side.



Figs. 867.—Midland Locomotive: Eccentrics. Scale 1/10th.

The bolt-heads are $1^{13}/_{16}$ inches square, ⅞ inch thick; the nuts are 1⅛ inches thick, and the jam-nuts ¾ inch. One of the half-straps of each eccentric is formed with a flat surface 8½ inches long, 3 inches wide, to which the eccentric-rod is fastened, with two 1¼-inch stud-bolts screwed into the strap for a depth of 2 inches, at 6-inch centres. Each bolt is secured with a $5/_{16}$-inch iron pin passed through it and the metal of the strap, and riveted over at each end. The free ends of the bolts are reduced to 1⅛ inches in diameter, and screwed for nuts, 1⅛ inches thick, with jam-nuts ¾ inch thick. A syphon oil-cup is cast on the strap, closed with a brass screw-plug. A $1/_{16}$-inch vent-hole is drilled through the plug for the escape of air while oil is poured in.

Each pair of eccentric-rods is 4 feet 3⅞ inches in total length, measured from the centre of the eccentric to the centre line of the expansion-link. The rods are rectangular, 1⅛ inches thick, 3½ inches wide at the strap, 2½ inches at the link. They are formed with palms, 1¼ inches thick, to join the eccentric-straps, and are forked at the other ends to take the expansion-link, to which they are pinned with plain 1¾-inch wrought-iron pins, secured in the forks by split-pins. The expansion-link is 17 inches long between the end centres, 2¼ inches thick, curved to the radius 4 feet 3⅞ inches, or the length of the eccentric-rods. The slot in the link is 2¾ inches wide, and the sliding block in the slot is of gun-metal, 3½ inches in length. The extreme vertical range, or lift and fall, of the expansion-link is 8 inches, or 4 inches above and 4 inches below the position of mid-gear. The block in the link is pinned with a 1¾-inch pin to the end of the prolongation of the valve-spindle, which is forked to receive it. The prolongation is a cylindrical expansion, 3½ inches in diameter, which is supported by and is guided in a gun-metal slide, 12 inches long, bolted to the motion-plate. The prolongation is cottered to the valve-spindle. The travel of the slide-valve in full gear forward or backward is, as before stated, $3^{13}/_{16}$ inches, and in mid gear it is 2¼ inches. The weigh-bar shaft, or reversing shaft, placed transversely above the link-motion, is 3½ inches in diameter at the middle, tapering to a diameter of 3 inches at each end. It has a cast-iron bearing bolted to each side frame-plate, with journals 2¾ inches in diameter, 3½ inches long. The two lifting arms on the shaft are 13 inches long, 1 inch thick, with 14-inch lifting links, pinned to the centre of the expansion-link, and 1¾-inch pins. The load on these arms is balanced by cheese-blocks of cast iron, one to each arm, 12 inches in diameter, 5½ inches thick, fastened with a sunk bolt and nut on an arm, at 12 inches of radius. All the pins are of best iron, case-hardened.

The whole of the link-motion work is behind the motion-plate.

The reversing arm on the weigh-bar shaft is 14 inches long, and is worked from the foot-plate by a rod and triple-thread screw, having 1½ inches of pitch, commanding a swivel-nut 6 inches long, pivoted on the end of the rod, and sliding on a bracket carrier of dovetail section; with a two-handle lever of 9 inches radius. The screw, handle, and rod are of best iron. The carrier and bracket are of malleable cast iron. All the

working parts are case-hardened. The bracket is placed on the top of the right-hand trailing splasher.

The distribution of steam by the valve-motion is as follows, the throw of the eccentric being 6 inches, the lap of the valves being 1 inch, and the lead $5/32$ inch, in full gear forward:—

Distribution by Valve-gear.

	Travel of Valve.	Front Port.				Back Port.			
FORWARD GEAR.		Lead.	Port Opens.	Cut Off.	Ex-haust.	Lead.	Port Opens.	Cut Off.	Ex-haust.
	inches.	inch.	inch.	per cent.	per cent.	inch.	inch.	per cent.	per cent.
Full gear........	$3\frac{7}{8}$	$5/32$	$13/16$ *f.*	$71\frac{2}{3}$	$91\frac{2}{3}$	$5/32$	$1\,1/32$ *f.*	$69\frac{1}{4}$	$89\frac{1}{4}$
Notch 2.........	$2\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{8}$ *f.*	$36\frac{1}{2}$	77	$\frac{1}{4}$	$\frac{1}{2}$ *b.*	$39\frac{1}{2}$	$74\frac{3}{4}$
Mid gear........	$2\,9/32$	$\frac{1}{4}$ *f.*	$\frac{1}{4}$ *f.*	11	$52\frac{1}{4}$	$\frac{1}{4}$ *f.*	$\frac{1}{4}$ *f.*	$12\frac{1}{4}$	$53\frac{1}{4}$
BACKWARD GEAR.									
Full gear........	$3\frac{7}{8}$	$\frac{1}{8}$	$13/16\ 1/32$	$71\frac{3}{4}$	$91\frac{5}{8}$	$\frac{1}{8}$	$1\,1/32$	$70\frac{1}{4}$	$90\frac{1}{2}$
Notch 2.........	$2\,13/16\ 1/32$	$\frac{1}{4}$ *b.*	$\frac{3}{8}\,1/32$	$36\frac{7}{8}$	76	$\frac{1}{4}$	$7/16$	$38\frac{1}{2}$	$75\frac{3}{4}$

Note:—*f* signifies *fully*, *b* signifies *barely*.

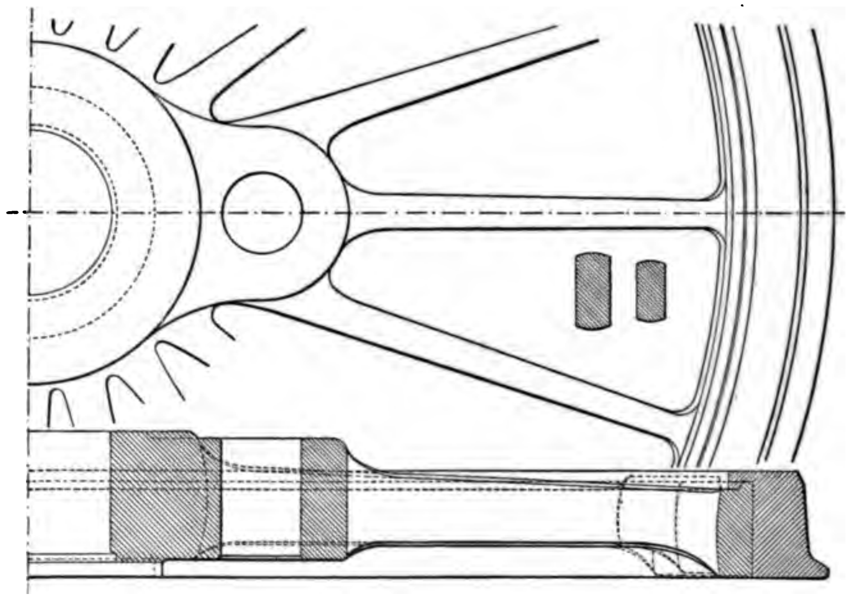
The driving and trailing axle-boxes are of solid gun-metal, or of wrought iron case-hardened, with gun-metal bearings. The slides or guides between which they are lodged are of chilled cast iron. They are of bracket-form, in pairs, planed or ground all over, and fixed 12 inches apart. They are of $1\frac{1}{4}$-inch metal, let into and bolted to the longitudinal frame-plates with seven 1-inch bolts and nuts to each driving-axle bracket, and five to each trailing-axle bracket. They are of length sufficient for $1\frac{3}{4}$ inches of play of the axle-boxes. The boxes bear direct on the axles, and are 2 inches thick over the journal. They are formed with flanges, 2 inches wide, $\frac{1}{2}$ inch thick, lapping the guides. The keeps are of wrought iron, lodged between and fitted to the flanks of the axle-boxes, and fastened to them with two $1\frac{1}{8}$-inch pins, transversely. The lower end of each keep is formed with an eye, $2\frac{1}{4}$ inches thick, to take the spring-buckle with a $1\frac{1}{2}$-inch pin. The lower ends of the guides under each axle-box are tied together by a wrought-iron plate, $1\frac{1}{4}$ inches thick, joggled on to them, and fastened with two $1\frac{1}{8}$-inch stud-bolts and nuts.

The bogie axle-boxes are of gun-metal, lined with white metal, fitted with cast-iron keeps. The guides are brackets of cast steel, fixed at $7\frac{1}{2}$ inches apart on the outside of the side frame-plates of the bogie, with six 1-inch bolts and nuts for each. The ends of the horns of the frame are tied by a bar notched on and bolted to each pair of horns.

The wheels are of wrought iron, solid-forged, from the very best selected scrap iron. The spokes are forged solid with segments of the rim, forming T heads, and the spokes are welded at the mid-length of each spoke. Counterweights are forged solid on the rims of the driving and trailing wheels, and these wheels are crank-bossed. Each wheel is placed on the

axle by hydraulic pressure, of not less than 70 tons, and secured by a key; and then the tyre is shrunk on the wheel.

The driving and trailing wheels, figs. 868 and 869, are 6 feet 9 inches in diameter. The rim is 6 feet 3 inches in diameter, $4^{15}/_{16}$ inches wide, 1¾ inches thick. There are 20 spokes in each wheel, 1¾ inches thick, 4 inches wide at the nave; 1½ inches thick, 3⅛ inches wide near the rim; pitched at about 13 inches between centres at the rim. The nave is 17½ inches in diameter, making 4½ inches of metal round the axle, and 6¾ inches wide. The rim is turned with a square fillet or lip on the inner edge to enter



Figs. 868.—Midland Locomotive: Driving and Trailing Wheels. Scale 1/10th.

the tyre. The crank-pin in each wheel, for coupling, is 4¼ inches in diameter within the boss, which is 6¼ inches deep, with 2¼ inches of metal round the pin. The pin is forced in by hydraulic pressure of from 35 to 40 tons; and it is riveted over at the end. It comes home on a ½-inch collar, next which is the journal, 3½ inches in diameter, 3½ inches long, case-hardened. The journal is closed by a wrought-iron 2½-inch flange-nut, case-hardened, $1^{11}/_{16}$ inches thick, screwed on with seven threads to the inch, and secured by a ½-inch steel split-pin, tapered at the rate of ⅛ inch in 6 inches, or 1 in 48.

The bogie-wheels are 3 feet 6½ inches in diameter. The rim is 3 feet ½ inch in diameter, allowing 3 inches for the thickness of the tyre; $4^{15}/_{16}$ inches wide, 1⅝ inches thick. There are ten spokes, landed on the rim at about 10½ inches of pitch. The nave is 6½ inches in diameter inside, 12 inches outside, making 2¾ inches of metal round the shaft, and 6¾ inches wide. The spokes are 1½ inches near the nave, tapered to 3¼ inches by 1¼ in

The tyres are of crucible cast steel, turned to the section shown in fig. 869 for all except the driving wheels; 5½ inches wide, 2¾ inches thick at the tread, which is inclined at the angle 1 in 26, bevelled at the outer edge for a width of ⅝ inch, and formed with a flange 1 inch thick, projecting 1¼ inches from the middle of the tread, rounded to a ½-inch radius, and joined to the tread with a curve of 13/16-inch radius. The tyre is grooved at the inner side to receive the fillet on the side of the rim, and is secured to the rim by twenty ⅞-inch screws, one to each interspace screwed through the rim into the tyre. The tyres on each pair of wheels are placed at a distance apart of 4 feet 5⅝ inches between the backs of them,—such that they have a total play of about ½ inch between the wheel-flanges and the rails. The tyres are shrunk on the wheels after these are forced on the axle. The tyres of the driving wheels differ from those for the other wheels, in having the flanges thinner—13/16 inch thick. The tyres of the leading and trailing wheels, as they wear, are turned down finally to a minimum thickness of 1⅝ inches; after which, when again worn, they are removed.

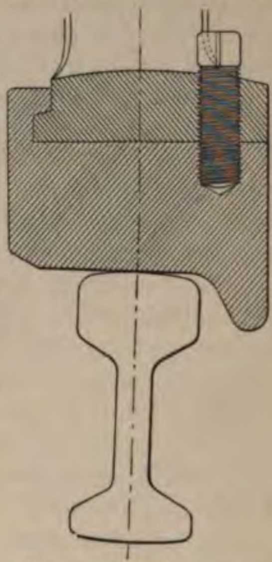


Fig. 869.—Midland Locomotive: Section of Wheel-tyre and Fastening. Scale 1/4th.

The wheels are fastened on the axles each with a steel key 1½ inches wide, 1⅛ inches thick.

The bearing springs are of the best spring-steel plates, with buckles of wrought iron. Those for the driving and trailing axle-boxes have 3 feet of span and 5¾ inches of camber, unloaded; or 3 feet 1¼ inches of span, and 3½ inches of camber, when loaded. They deflect at the rate of 5/16 inch per ton of load on each spring. They are suspended from the axle-boxes, and are pinned by the buckle to the keep, as before stated. The buckle is 4 inches wide, 11/16 inch thick at the sides, 1⅛ inch at the bottom; forked at the upper side, with limbs 1⅜ inches thick, to receive and take the lower end of the keep with a 1½-inch wrought-iron pin. The ends of the spring are linked with strut-links, 6 inches long, to the side frame-plates, with 1¼-inch pins through eyes formed on the ends of the upper plate of the spring, and 1⅛-inch pins through the frame-plates. Each spring consists of 22 plates, 4½ inches wide, of which the top plate is ½ inch thick and the other plates 5/16 inch, making together a depth of 7 1/16 inches of spring at the buckle. The lowest plate is 10½ inches long. The bogie-springs, in an inverted position, have 3½ feet of span, unloaded or loaded; and 5 inches and 3¼ inches of camber, respectively. Their deflection is ¼ inch per ton of load on each spring. They have each 11 plates ½ inch thick, 5 inches wide, making a total depth of 5½ inches of spring at the buckle. The buckle is of wrought iron, 4 inches wide, ⅝ inch thick at the sides, 1⅛ inches at the top; and is fitted with a 2¾-inch pin on the under side, taking the cradle and the frame-plate, the

whole being fastened together with a nut on the inner end of the pin. The ends of the spring are linked to the cradle with 1¼-inch pins, and the load is transferred to the axle-boxes in the manner already described in the notice of the bogie.

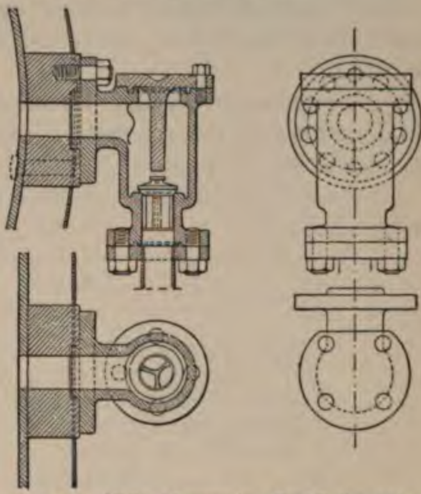
The engine is fitted with a steam break, consisting of cast-iron break-blocks, wrought-iron hangers, carriers, rods, and cross-bars, for the driving and trailing wheels; also a horizontal 9-inch steam cylinder, single-acting, with piston and levers, fixed below the draw-plate, and connected with the break-gear. The piston-rod is linked to the end of a lever having 10-inch and 4½-inch arms connected to the lower ends of the hangers, two of which are applied, one for each driving-wheel. The break-blocks are swivelled, one to each hanger, at mid-length; and thus the leverage of the piston is increased to $\left(\frac{10}{4\frac{1}{2}} \times \frac{2}{1} = \right)$ 4.44, multiplying the pressure on the piston 4.44 times. By the action of a helical spring, fitted below the steam-cylinder, the lever, and with it the piston, are pulled back, when the steam is exhausted.

For the vacuum-break, a large ejector, with a Gresham valve, is fitted on the side of the smoke-box, together with a gun-metal steam-valve, seating, gearing, and clappet-valve, fixed to the hand-rail. In addition, there is a combined automatic ejector and blower with clappet-valve, fixed on the back of the fire-box, with an exhaust steam-pipe passing through the boiler to the cap of the blast-pipe. The combined steam and vacuum-break valve for applying or releasing the breaks, clappet-valves, and steam-valves are provided. Also a Bourdon's vacuum-gauge and union. A gun-metal elbow-pipe, with a brass tube for conveying steam to the tender-break, is fixed on the back of the fire-box. India-rubber hose-pipes and couplings are provided for the vacuum-break, between the engine and tender, and at the back of the tender.

Boiler Mountings.—Mountings are fixed on flat seatings, as shown. These are:—One Bourdon's pressure-gauge to indicate pressures up to 200 lbs. per square inch; one large and one small whistle and stand; stand and gear to connect with cord communication; two water-gauge cocks; one set of glass water-gauge cocks; one steam-break stop-cock, with a copper pipe in the boiler reaching to the top of the dome; two injector steam-cocks and copper pipes to the top of the dome; two injector clack-boxes; two of Furniss's cylinder lubricators; one No. 3 Roscoe's lubricator. All these are of gun metal. The clack-boxes are shown in figs. 870. The valve is three-leaved, 1¾ inches in diameter, and 1¾ inches long in the leaves. It seats at the angle 45°, with a bearing 1/16 inch broad, and a lift of 5/16 inch. The feed-pipe is of copper, 1½ inches in diameter, No. 9 B.W.G. (⅛ inch) in thickness. The body of the clack-box is ½ inch thick, and 3 inches in diameter inside. It delivers to the boiler by a 1¾-inch thoroughfare. A wrought-iron seat, 7 inches in diameter, is riveted to the boiler; and to this the clack-box is fixed with four ¾-inch screws. The buffers, at the front, consist of wrought-iron cases, with

Spencer's india-rubber washers (No. 2 cylinder). The plunger-head is 7⅜ inches in diameter; and the projection of the buffer-head from the buffer-beam, when fixed, is 17½ inches. The buffers are 5 feet 8 inches apart horizontally, between centre-lines, and they are 3 feet 5 inches above the level of the rails. The draw-hook at the front is mounted with Spencer's No. 6 A india-rubber spring. It is fitted with a shackle of 1½-inch round iron, two links of 1⅜-inch round iron, and a hook.

Two wrought-iron rail-guards are fixed with palms, one to each longitudinal frame-plate, descending to the level of 2½ inches above the rails.



Figs. 870.—Midland Locomotive: Feed Delivery-pipe and Clack-box. Scale 1/10th.

Lagging.—The boiler and the firebox-shell are lagged with well-seasoned pine, covered with smooth iron sheets, No. 14 B.W.G. in thickness, which are fixed on hoops. The thickness of the clothing on the fire-box is 1½ inches, increasing towards the smoke-box, as it is carried cylindrically over the barrel.

The *dome-casing* is of copper or iron, painted. The funnel of the safety-valve, on the fire-box, is of polished brass, No. 14 B.W.G. in thickness.

Injectors.—There are two brass injectors, Gresham & Craven's, class G. The right-hand injector is No. 8 mm., and the left-hand injector is No. 7 mm., placed in a No. 8 casing. They are fitted with stop back-valves and waste-cocks. The feed-pipe is connected to the tender by a ball-and-socket joint. The pipes are of copper, No. 9 B.W.G. in thickness, solid drawn. The feed-pipe from the tender to the injector is 1¾ inches in diameter; the delivery-pipe to the clack-box, figs. 870, 1½ inches; the steam-pipe to the injector, 1¼ inches; the overflow-pipe, 1¼ inches.

Sand-boxes.—Two sand-boxes of cast iron, about 16 inches square each, are fixed between the inner and outer longitudinal frame-plates, with a pipe from each descending to within 2½ inches above the rails. The supply is regulated or shut off by means of a rotating butterfly valve at the bottom of each box, on a vertical spindle, worked from the foot-plate.

The *cab* is of best Staffordshire plate, fully ⅛ inch thick. It has two plate-glass windows, 14 inches net in diameter, fitted in brass frames; hinged, to open. All rivets are countersunk and filed smooth. The trailing splasher is riveted to the side of the cab, and strengthened to take the stress of the reversing screw.

Splashers to be of plate iron, fully ⅛ inch thick; neatly finished with a brass beading at the outer curves; rivets countersunk and filed smooth.

The *hand-rail* is of polished iron tubing, 1¼ inches in diameter; attached

to the boiler with polished wrought-iron pillars and carriers fixed on the boiler. The hand-rail is laid round the smoke-box.

Lamp-holders are fixed on the foot-plate and the smoke-box—one on the top of the smoke-box in front of the chimney, one on each side of the platform at the front, one on the top of the cab at the back to carry the hand-lamp, and one on the back of the fire-box for the gauge-lamp.

Bolts and Nuts.—Threads and sizes to be to the Whitworth standard. Gland nuts and cylinder-cover nuts are case-hardened; nuts inside the smoke-box are of hard brass, and have "blind ends," or are closed at the outside.

Proportions of Threads (brass work).—14 threads per inch up to 1 inch in diameter; 11 threads from 1 inch to 2 inches; 8 threads above 2 inches; copper stays, 11 threads.

Copper Pipes.—These are solid drawn, and are here tabulated for easy reference:—

Pipe.	Diameter.	Thickness.
	inches.	B.W.G.
Steam-pipe in boiler	4	7
Do. smoke-box	4	7
Delivery-pipe to clack-box	1½	9
Injector steam-pipe	1¼	9
Blower-pipe in boiler	1	9
Do. smoke-box	1½	9
Lubricator pipes to axle-boxes	⅜	10
Do. smoke-box	⅜	8
Connecting feed-pipe to tender	1¾	9
Steam-break pipes	⅝	9
Main air-pipe of vacuum break	—	10
Steam-pipe, large ejector	—	9
Air-pipe, small ejector	1	14

Tools.—There are provided a complete set of double-ended screw-keys and gland-keys, case-hardened and finished bright, stamped with the railway company's initials and the number of the engine; with special spanners for eccentric-bolts and coupling-rods; one heavy and one small hammer, one lead and one copper hammer; one large and one small pin punch, two drifts, three chisels, one steel-pointed crowbar, one small steel pinch-bar, one gland-packing bar, one screw-jack, one 1-gallon oil bottle, one ½-gallon oil bottle, one large and one small oil-feeder; one fog-signal case; one shovel, one coal pick, one hand-brush, one working time-table case; all the necessary fire-irons; a tube cleaner; also a chain, carrier, and padlock.

Painting.—The boiler receives two coats of oxalic paint before being lagged. Frames, splashers, hand-rails, an [illegible] coats of oxalic paint, two coats of green, finish boiler, after being lagged, the frames screen, one coat of lead colour, two c

up, properly rubbed down, two coats of lead colour, sand-papered, two coats of green, picked out with black, and fine-lined with white. The rims of the tyres are black, with a white line. The insides of the frames and the axles are finished with one coat of vermilion and one coat of varnish. Inside frames, sand-boxes, guards, &c., finished brown, picked out with white. Buffer beams and buffers finished vermilion and varnished. The initials, M. R., painted on in large block letters. The smoke-box, chimney, back of the fire-box, platforms, and steps painted black, two coats. The inside of the cab to be prepared similarly to the boiler and frame, and finished in brown and lined.

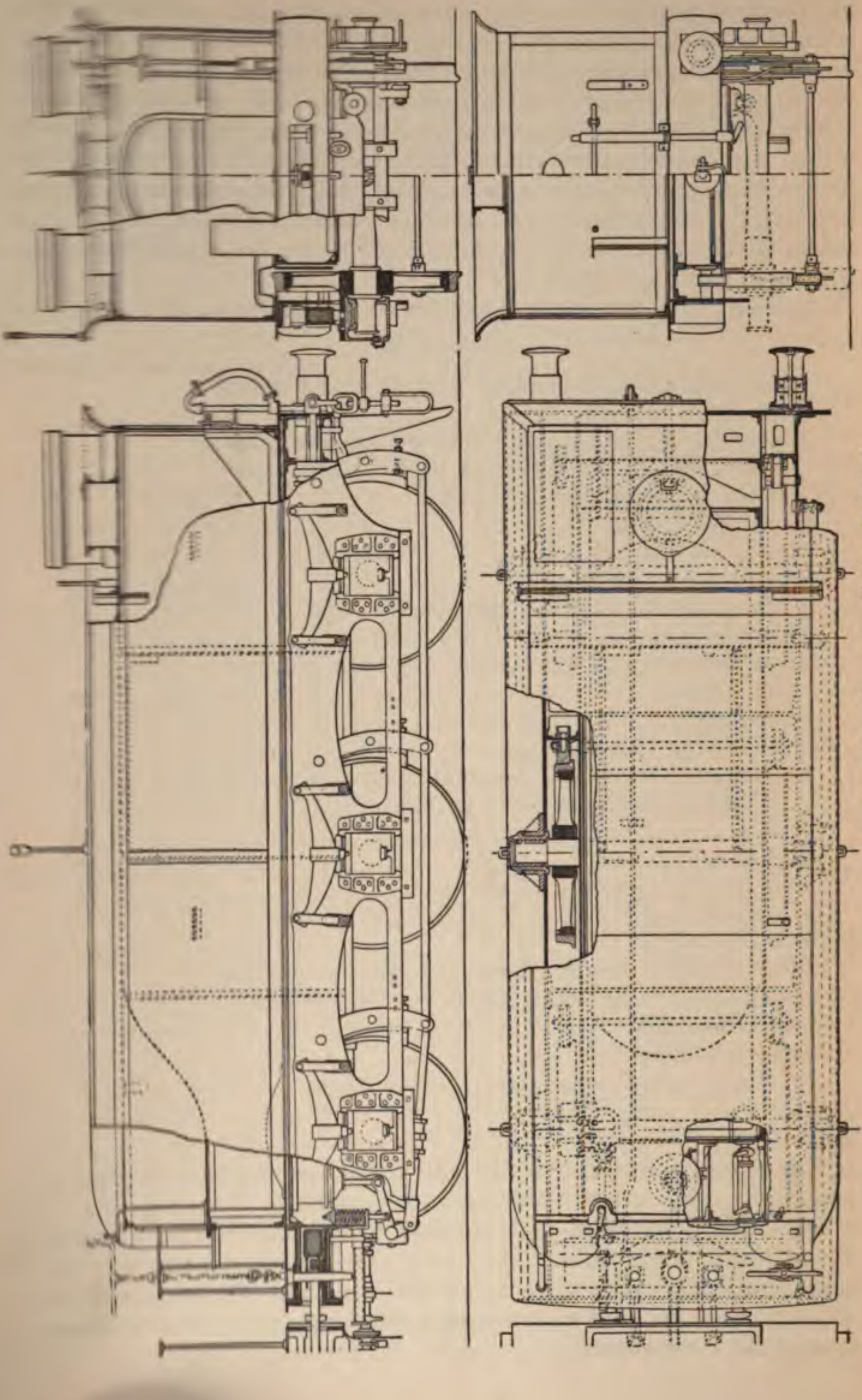
The weights of the principal members of the engine are as follows:—

Weights of Parts.

	tons.	cwts.	qrs.	lbs.
Inside longitudinal frame-plates, horn-stays, and spring-hangers	2	5	1	15
Frame complete, including inside frame-plates with attachments, cross-plates, buffer-beams, diagonal plates, gusset-plates, motion-plate, &c., and angle-irons	5	15	3	16
Crank axle, hooped	0	18	3	24
Trailing axle	0	8	1	16
1 pair of driving wheels and tires	2	19	2	0
1 pair of bearing springs for driving (buckle extra)	0	4	1	18
1 pair of driving axle-boxes (iron and brass)	0	6	1	8
Bogie complete, with wheels, axles, axle-boxes, and bearing springs	4	16	1	0
1 bogie axle	0	5	0	12
1 pair of bogie wheels and tires	1	0	1	16
1 pair of bogie springs (buckles extra)	0	4	3	0
1 pair of bogie axle-boxes with keep (brass)	0	1	2	22
1 piston	0	1	1	16
1 piston-rod	0	0	3	0
1 crosshead and pin, with slide-blocks	0	4	0	10
1 connecting-rod, complete	0	3	1	24
1 coupling-rod	0	2	0	0
Link-motion and reversing screw (including valve-motion and eccentrics for both cylinders, and reversing shaft and connections)	0	16	2	15
Boiler and fittings	10	2	0	0
Total weight of the engine (as before stated)	38	11	0	0

TENDER.

The tender, figs. 871, is made with six wheels, and to hold 3000 gallons, or 481 cubic feet, or over 13 tons, of water, and from 3½ to 4 tons of coal. The frame is of Yorkshire iron, frame-plate quality. It consists of four longitudinal plates, two at each side, riveted together with horizontal cross-plates at the front and the back, and with horizontal stay-plates between the frame-plates at each side above the vertical cross-plate between the frame-plates.



Figs. 871.—Midland Locomotive: Tender. Scale 1/50th.

The weight of the tender empty is 18 tons 17 cwts.; full, with 2 tons of coal, 33 tons 19 cwts.

The outer side frame-plates are 1 inch thick and 2 feet 9 inches deep, relieved by large openings between the axle-box guides. They are 20 feet 8 inches long, and are 5 feet 9½ inches apart. The inner side frame-plates are 14½ inches deep, ⅝ inch thick, and 4 feet 2¾ inches apart. The horizontal stay-plates are ½ inch thick. The ends or buffer-plates are 1¼ inches thick, 15 inches deep, and 7 feet 5 inches wide. The outer side plates are tied together at the lower side edge with two cross bars, made with a palm at each end, by which they are united to the plates with four bolts and nuts. The top of the frame is 4 feet 2¼ inches above the level of the rails.

The axles are 6½ feet apart between centres, making a wheel-base of 13 feet.

Tank.—The tank is made with a well; and is of BB Staffordshire iron-plate. Each side is in two plates, with butt-joints and strips on the outside. The inside is stayed with three vertical cross plates and angle-irons to the bottom of the tank, also connected to the well-tank. The tank is made distinct from the frame, and may be readily lifted for examination or repair.

The tank proper is 18 feet 7¼ inches long, 6 feet 7 inches wide, 3 feet 9 inches high above the frame. The well is 14 feet 8 inches long inside, 4 feet 1¼ inches wide, 17⅛ inches deep. The plates are ¼ inch thick for the top, sides, and ends; ⅜ inch for the bottom and the well plates; 5/16 inch for the vertical stays in the tank, and for the sides of the well; ⅜ inch for the horizontal stays of the tank. The angle-iron for the sides, top, and ends is 2 inches by 2 inches by ⅜ inch in section; and the inside angle-iron for fixing the tank to the bottom plate is 3½ inches by 2½ inches by ⅜ inch. The rivets are ½ inch in diameter, at 1¾ inches of pitch. The manhole is 18 inches in diameter, and stands 9 inches above the tank. The outside butt-straps, bottom edge and sides, are 3½ inches wide, ⅜ inch thick. The coping is 9 inches high.

The *axle-boxes* are of cast iron with gun-metal bearings and wrought-iron covers, case-hardened and polished. The keep is arranged for feeding oil below the axle. The guides are of cast iron. Bolts for keeps have split-pins through their ends.

Springs.—The bearing springs, one to each axle-box, are 2 feet 11⅛ inches in span, unloaded, with a camber of 5¼ inches. Loaded, the span is 3 feet. There are 18 plates, 4 inches wide, of which the top plate is ½ inch thick and the others ⅜ inch. The spring is 6⅞ inches deep at the buckle. The deflection per ton of load on each spring is ¼ inch.

The draw-spring between the engine and tender is a C spring of 18 plates, 6½ inches deep in all, and 3 feet span. The spring acts for both buffing and drawing. The draw-spring at the hind end is of Spencer's india-rubber, No. 6 A. The buffers are uniform with those on the engine.

Wheels and Axles.—The wheels are of wrought iron, 4 feet 3 inches in diameter, constructed like the engine wheels. The rim is 3 feet 9 inches in diameter, 4 15/16 inches wide, 1¾ inches thick. There are twelve spokes, 1½ inches thick at the nave, 1¼ inches at the rim; landed on the rim at 10 inches pitch. The nave is 15 inches in diameter, 6¾ inches thick, with a 7½-inch hole for the axle. The tyres are like those of the engine wheels, and are fastened similarly.

The axles are of best Yorkshire iron, 6⅜ inches in diameter at the middle, swelled to 7 inches at the back of the wheel, with a collar; 7½ inches in the wheel. The journals are outside the wheels, and are 5½ inches in diameter, 9 inches long.

Break.—A cast-iron break block, on a wrought-iron hanger, is applied for each wheel. The break shaft is connected to a steam-break cylinder, with a brass piston. Steam is supplied from the steam-pipe of the engine through a flexible brass pipe and stuffing-box. A 2⅛-inch copper pipe, connected with the engine, is laid under the tank, and brought up at the back of the tender, for fixing thereon the india-rubber hose pipe and coupling.

The weights of principal parts of the tender are as follows:—

	cwts.	qrs.	lbs.	tons.	cwts.	qrs.	lbs.
Frame, including axle-box slides and spring-carriers...				1	18	3	13
1 pair of wheels:—2 wheel-centres.........	13	2	10				
2 tyres....................	12	3	16				
				1	6	1	26
1 axle				0	7	3	6
1 spring				0	2	0	24

Painting.—The inside of the tank received two coats of thick red lead. The outside of the tank is prepared and finished like the boiler covering of the engine. The wheels and the outside of the frame-plates are finished like those of the engine. The inside of the frames have two coats of lead colour. The coal space, foot-plate, lower tank, the bottom of the tank and the break-work under the tender, have two coats of black.

Since the Midland locomotive just described was designed, Mr. Johnson has constructed a number of locomotives of similar design, but with 7-feet driving-wheels, and 1261 square feet of heating surface, with a pressure of 160 lbs. per square inch in the boiler. In 1887, he constructed a single express bogie locomotive for fast trains, having 18-inch cylinders, with a stroke of 26 inches, and 7-feet-4-inch driving-wheels; 1240½ square feet of heating surface, 19.68 square feet of fire-grate; 160 lbs. pressure per square inch in the boiler. The engine weighs 43 tons 13¾ cwts. in working order, of which 17½ tons is driving weight. This class was constructed for working the London and Nottingham express traffic at speeds of from 50 to 53 miles per hour, over ruling gradients of 1 in 120, with an average train of nine carriages, making with the en[illegible] and [illegible]oss weight

of 170 tons. The fuel consumed is, it is stated, from 20 lbs. to 21 lbs. of Derbyshire coal per mile.

According to Mr. Johnson's latest design (1889), differing from the preceding single-wheel engine only in some details, illustrated by fig. 872, the cylinders are 18½ inches in diameter, with a stroke of 26 inches; 7½-feet single driving wheels, 3½-feet bogie wheels, and 4-feet-4-inch hind wheels; working pressure 160 lbs. per square inch. The lap of the slide-valves is 1 inch; the lead is ⅛ inch fully. The barrel of the boiler is 10 feet 4 inches long, with 4 feet 2 inches mean diameter outside. The fire-box is 6½ feet long outside. There are 244 flue-tubes, of which 242

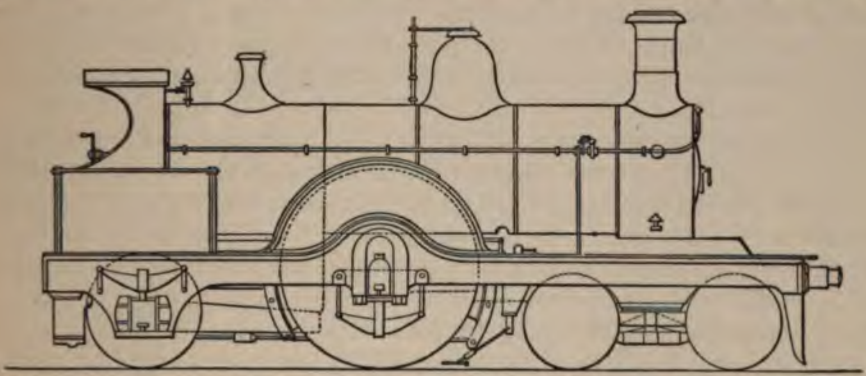


Fig. 872.—Midland Railway: Mr. Johnson's latest design (1889), Single-wheel Express Locomotive. Scale 1/84th.

are 1⅝ inches in diameter externally, and 2 are 1½ inches. The heating surface of the fire-box is 117 square feet, and that of the tubes is 1123½ square feet; together, 1240½ square feet, or 63.3 times the grate-area, which is 19.6 square feet. The bogie centre is 10 feet ½ inch from the driving centre; and this is 8 feet 9 inches from the hind-wheel centre, making 18 feet 9½ inches of fixed wheel-base of the engine. The bogie-wheel centres are 6 feet apart. The wheel-base of the engine and tender together is 43 feet 2¼ inches. The weight of the engine in working order is 43 tons, of which 17½ tons is driving weight. The tender has 3250 gallons capacity for 14½ tons of water, and can hold 3½ tons of coal. It weighs 30 tons when full, of which the weight empty is 12 tons. On the London and Nottingham traffic the average gross load is from 170 to 215 tons, of which the equivalent in vehicles is from 9 to 12 carriages. The time-bill speed is 53½ miles per hour; the longest continuous run is 124 miles; and the coal, Derbyshire, is consumed at the rate of from 20 lbs. to 23 lbs. per mile run.

CHAPTER LXIII.—FOUR-COUPLED PASSENGER LOCOMOTIVE, WITH TENDER.

DESIGNED BY MR. WILLIAM COWAN FOR THE GREAT NORTH OF SCOTLAND RAILWAY; CONSTRUCTED BY MESSRS. NEILSON & CO., GLASGOW.

PLATE XV.

(Cylinders, outside, 17½ inches by 26 inches; coupled-wheels 6 feet 1 inch. Gauge of way 4 feet 8½ inches.)

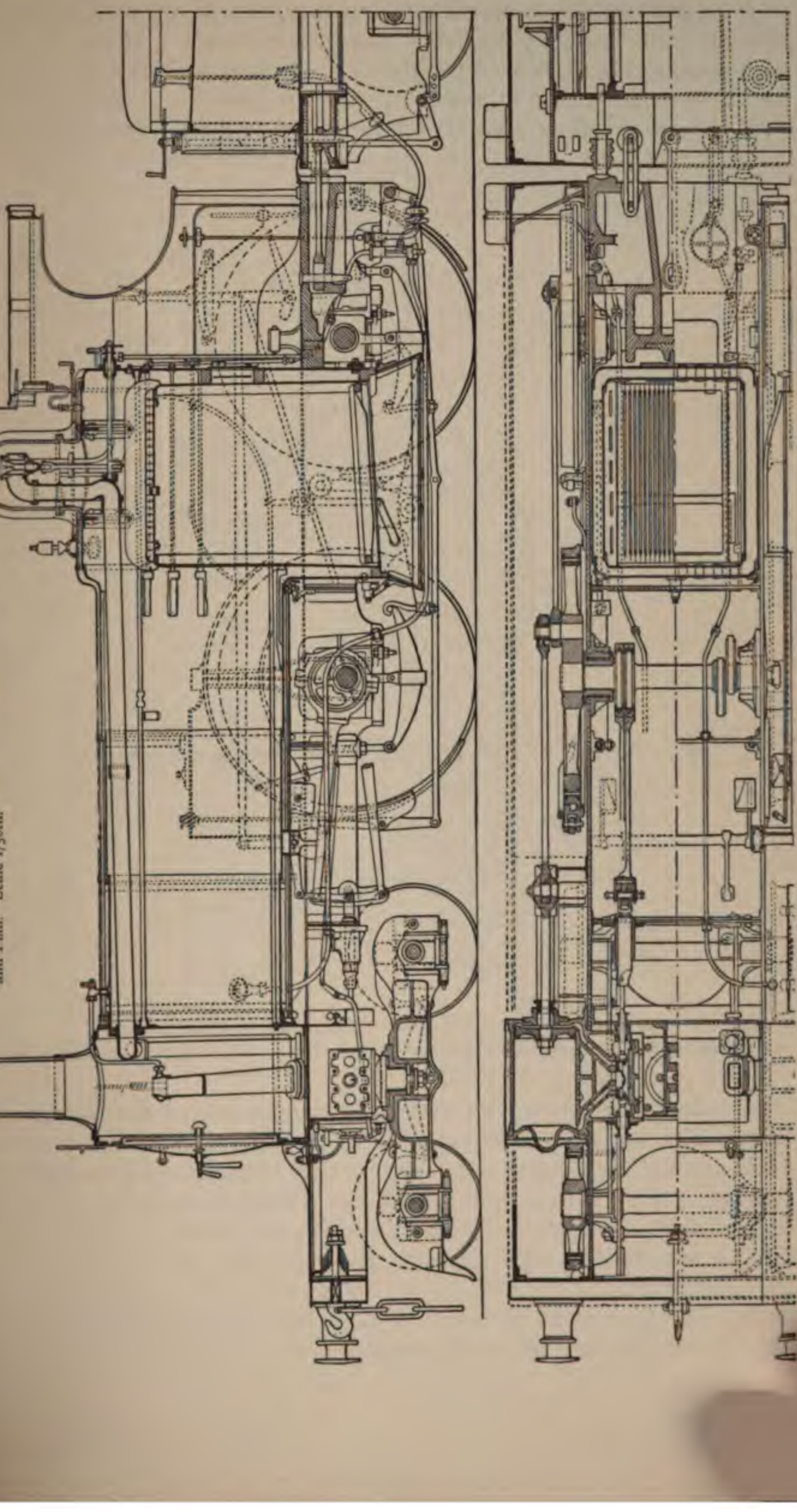
The general arrangement and design of this locomotive are shown in figs. 873, 874, and 875, and Plate XV. The cylinders are outside and horizontal, with four coupled wheels behind and a four-wheel bogie at the front, with inside bearings. Though the general disposition resembles that of the Midland passenger locomotive already noticed, the design and detail are very different.

In this engine the coupled axles are 8 feet apart, and the centre of the bogie is 9½ feet from the driving axle, making a wheel-base of (8+9½=) 17½ feet from the centre of the bogie to the trailing axle. The bogie wheels are 6 feet apart, and the total wheel-base is (17½+3=) 20½ feet. The driving and trailing axles are placed as much forward as is consistent with providing for a sufficient length of connecting-rod, in order to secure a proper proportion of the weight for tractive purposes. The trailing axle is only 8 inches behind the firebox-shell, whilst the driving axle is 28 inches in front of it; and the co-operation of a heavy cast-iron platform behind the boiler is wanted, in order to complement the load on the trailing axle, or, more generally stated, to shift the centre of gravity of the engine farther back, towards the driving and coupled axles. The results of such combination are that the weight of the engine, when it is full, is distributed nearly equally on the three points of bearing—the trailing axle, the driving axle, and the bogie, as follows:—

	Empty.		Full.	
	tons.	cwts.	tons.	cwts.
Bogie	13	1	14	0
Driving axle	11	7	12	15
Trailing axle	11	7	12	15
	35	15	39	10
Tender	15	0	27	0
	50	15	66	10

By the rule for finding the position of the centre of gravity horizontally,[1] the products of the loads on the bogie and the hind axles by their respective distances from the middle axle, are (14×9½=) 133, and (12.75×8=) 102. The difference is 31, and the quotient of this difference divided by the total weight of the engine is .785 foot, or 9.42 inches, which is the position horizontally of the centre of gravity in advance of the driving axle; and, as it happens, it is almost exactly half-way between the bogie-pin and the trailing axle.

[1] *Railway Machinery*, page 189.



Figs. 873.—Great North of Scotland Railway: Four-coupled Passenger Locomotive. Sectional Elevation and Plan. Scale 1/56th.

The working steam-pressure is 150 lbs. per square inch. The area of the fire-grate is 14 square feet. The heating surface of the fire-box is 84 square feet, and that of the flue-tubes is 1023.4 square feet; together, 1107.4 square feet, or 79 times the area of fire-grate.

The frame of the engine is of Krupp's frame-plate. It consists of four

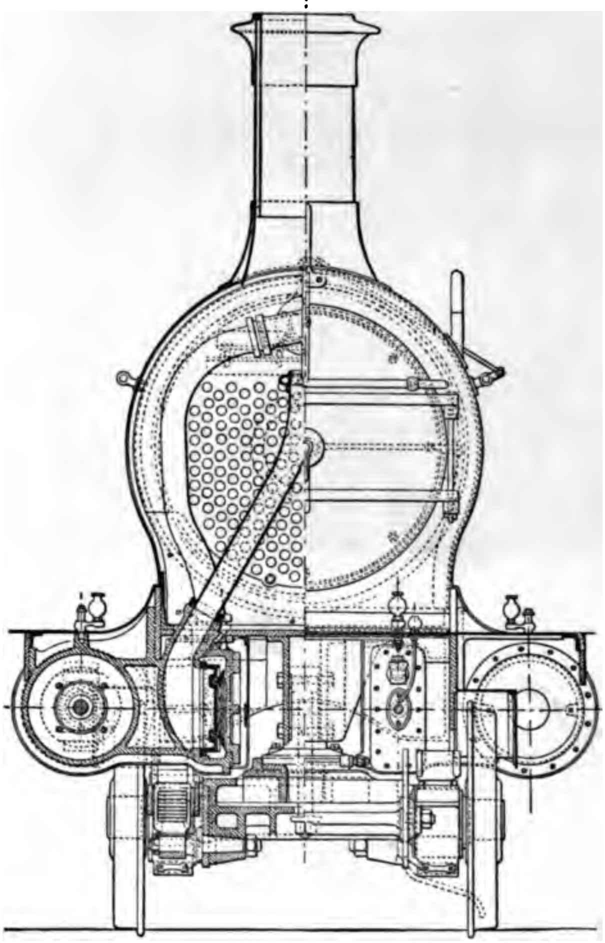


Fig. 874.—Great North of Scotland Railway: Passenger Locomotive. Front Elevation and Section of Smoke-box and Cylinders. Scale 1/32d.

longitudinal side-plates, with five transverse plates and the cast-iron platform. The two main side-plates, to which the principal attachments are made, are 1¼ inches thick, 25 feet 10 inches long, placed 4 feet apart, and standing 4 feet 1 inch high above the level of the rails. They are 15 inches deep at the part between the cylinders and the driving axle, and over the driving and trailing axle-boxes; 12 inches deep at the cylinders, and 20¼ inches deep at the sides of the firebox-shell. The plates are recessed or reduced ½ inch in thickness to clear the leading bogie-wheels. The axle-guards are tied by cross-bars slotted on to them. The outer side-

plates are ¾ inch thick, 8 inches deep, 20½ inches clear of the inner side-plates, measuring 7 feet 9 inches in width over the plates. The four side-plates are bound together by the buffer-plate, ⅝ inch thick, 16 inches deep. The inside plates are bound together by a transverse plate forming part of the bogie-fastenings, 9/16 inch thick, 12 inches deep at the centre, and 18½ inches at the sides where it joins the side-plates. It is flanged at the

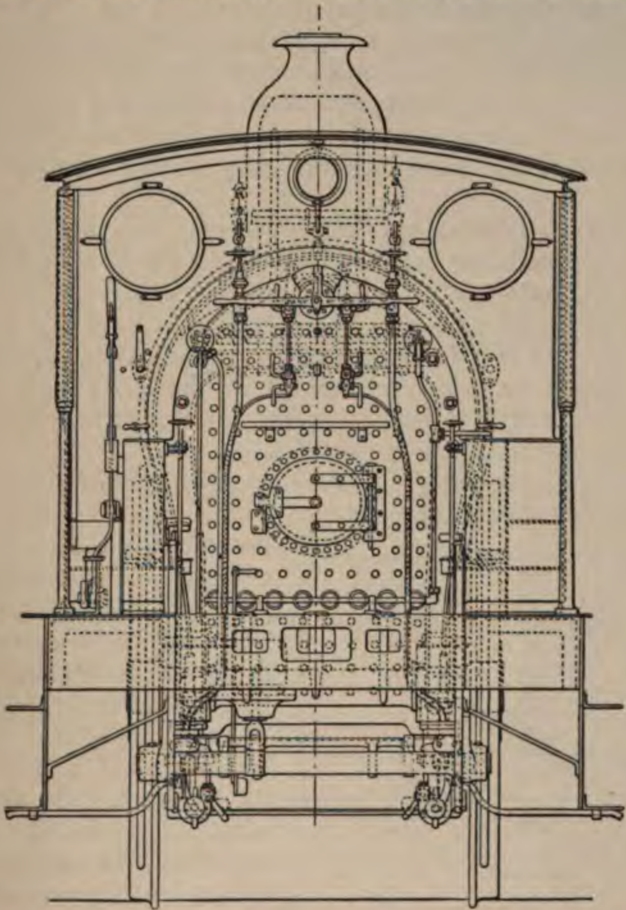


Fig. 875.—Great North of Scotland Railway: Passenger Locomotive. Back Elevation of Fire-box End. Scale 1/32d.

lower side and the ends, 5 inches wide. Next comes the motion-plate ⅞ inch thick, 12 inches deep, joined to the side-plates with 3-inch angle-irons; then a plate 1¼ inches thick, 8¼ inches deep, in advance of the driving-axle; and another plate, 1¼ inches thick, 15 inches deep, just in front of the firebox-shell. Lastly, a massive cast-iron platform or foot-plate of 2½-inch metal, weighing 33 cwts., behind the fire-box, forming a draw-chamber.

The inner and outer side-plates at each side are bound together by the front buffer-beam, as before noted; the cylinder, the guide-bar bracket, or

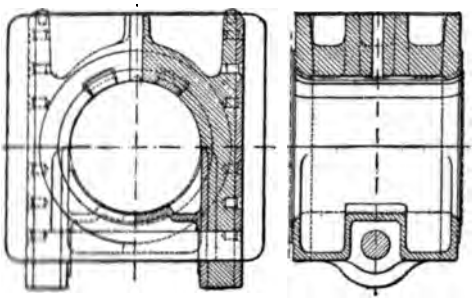
motion-plate, which is of steel, and an end plate at the back; also by the side foot-plates or platforms, which are of ¼-inch iron plate. The platform in front of the smoke-box is of ½-inch plate.

The main side-plates are also bound by a 1-inch horizontal plate, 33 inches wide, fitted between the side-plates, under the smoke-box, and acting as a base for the bogie fastenings. It is joined to the side-plates with 4-inch angle-iron, ⅝ inch thick.

A buffer-beam of Moulmein teak, 16 inches by 6 inches, 8 feet long, is bolted to the front buffer-plate, and is covered on the front with a 5/16-inch iron-plate, turned over the ends. A draw-hook is passed through the beam, bearing on a volute spring at the inner side of the beam. Two buffers are fixed on the beam at 5-feet-8-inch centres, 3½ feet above the level of the rails.

The axle-box guides are cast-iron brackets, 7 inches wide on the faces, each pair of guides being cast in one piece, in which the guides are connected over the axle-box. The ruling thickness of metal is 1¼ inches. The hinder guide of each axle-box is fitted with an adjusting wedge, tapered at the rate of 1 in 16, inserted and adjusted by a 1¼-inch screw and double-nuts from below, and secured to the guide by a ¾-inch bolt and nut. Each casting is fastened to the frame-plate with fourteen 1-inch bolts and nuts, placed zigzag at the sides.

The driving and trailing axle-boxes, figs. 876, are of gun-metal, bored to a diameter of 7 1/16 inches, for 7-inch journals, and 9 inches long. The brass is faced at each outer side with ⅜-inch steel wearing plates, 7⅛ inches wide, fixed to it with ten countersunk screws: making up a longitudinal width of 11½ inches between the guide-brackets. The wearing plates are grooved with diagonal cuts to distribute the lubricant. The brass is lined with white-metal. The total depth of the axle-box is 13 inches, and it has a lubricator-chamber at the top with a ⅝-inch syphon hole to the crown of the journal. A brass keep is applied below the journal, and is kept in place with a 1½-inch longitudinal bolt, from which the spring is suspended. The four bearing springs, driving and trailing, are 3 feet 4 inches in span, with 2¼ inches of camber; they consist of 15 plates, 5 inches wide, of which 14 plates are ⅜ inch, and 1 plate, the uppermost, is ½ inch thick. The suspending bolt is formed with an eye to take the spring shackle, with a 1¾-inch pin, and an eye, 6¾ inches long, fitted between the sides of the keep, to take the 1½-inch longitudinal bolt. The two springs at each side of the engine take a bearing at their outer ends on the side frame plate. The inner ends are linked to the ends of an equili-

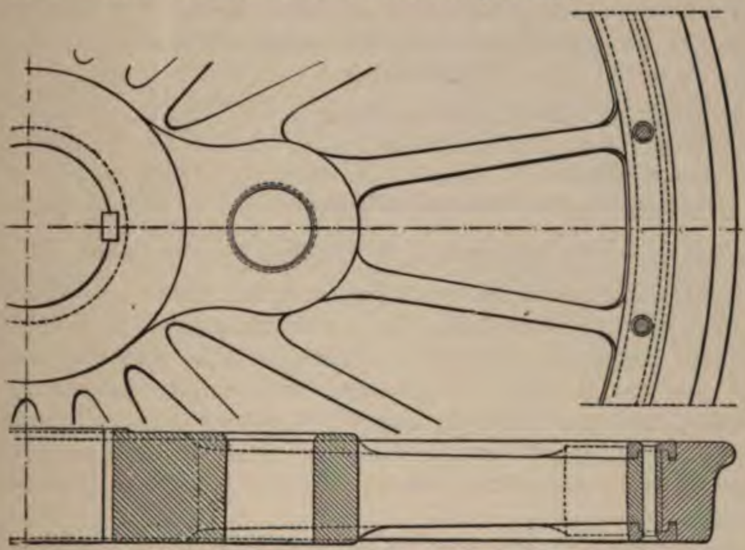


Figs. 876. "Great North" Locomotive: Driving Axle-boxes. Scale 1/10th.

brium lever, 4 feet 9 inches long, between the end centres, for the purpose of equilibrating the loads on the driving and trailing axles. The bearings of the spring-links are spherical, and adapt themselves to the swaying of the springs while the engine is in motion.

The driving and trailing axles are of Krupp's crucible steel, 6½ inches in diameter in the body, 7 inches at the journals and in the eccentrics for the valve motion; and 8½ inches in the wheels, tapering to 8 7/16 inches, or at the rate of 1 in 100 in a length of 6 inches. The journals are 9 inches long, and are 3 feet 7½ inches apart from centre to centre of lengths, and 2¼ inches within the respective side frame-plates.

The driving and trailing wheels, figs. 877, are of wrought iron, 6 feet 1 inch in diameter. The rim of each wheel is 5 feet 7½ inches in diameter.



Figs. 877.—"Great North" Locomotive: Driving and Trailing Wheels. Scale 1/10th.

It is 1¾ inches thick, 4¼ inches wide, reduced at the inner side to 3½ inches wide, to form notches to receive the retaining rings. The tyre is of Krupp's crucible steel, 2¾ inches thick at the tread, with a flange 1 1/16 inches thick, projecting 1⅛ inches, and connected to the tread with a curve of 1-inch radius. It is conical for a breadth of 2¾ inches, sloping 3/32 inch, or 1 in 29. It is bored to a diameter 1/1000th part of the external diameter less than that of the wheel, and is shrunk on. It is grooved in each face to receive two wrought-iron retaining rings, one at each side, which are fastened to the rim with ¾-inch through bolts, countersunk into each ring, one at the end of each spoke. The spokes, twenty in number, are 4¼ inches by 1⅝ inches thick near the nave, tapered to 3½ inches by 1¼ inches near the rim. They are pitched on the rim at intervals of about 10 inches. The nave is 16¾ inches in diameter outside, bored to 8½ inches, slightly taper, to receive the axle, as before noted; making 4⅛ inches of metal round the axle, and 6 inches along the axle. The wheel is fastened

to the axle with one steel key, 1⅛ inches by ⅞ inch thick, let half into the nave and half into the axle. A crank-boss is forged solid with four of the spokes, 5⅞ inches deep, bored to 4½ inches in diameter, tapered inwards to 4⅜ inches, at the rate of about 1 in 50, to receive the crank-pin; with 2⅜ inches of metal round the pin. The crank-pins are of iron case-hardened. They have 4½-inch journals, 3 inches long, for the coupling-rods; and the driving crank-pin has an overhung journal, 3½ inches by 4 inches, for the connecting-rod. The trailing crank-pin is fitted with a flange-nut to form a collar, screwed on and secured with a split pin. The pins are case-hardened, and are riveted over the boss. Counterweights of crescent form are welded between the spokes at the rim, of which the heavier counterweight is lodged in the driving wheels.

The counterweighting has been calculated to balance 81 per cent of the otherwise unbalanced revolving and reciprocating parts. These are, for each side of the engine, as follows:—

	Pounds.
2 cranks and pins, driving and trailing	207
1 coupling-rod	225
1 connecting-rod	201
1 piston, rod, crosshead, and slide-blocks	345
Total revolving and reciprocating weight	978

The length of the cranks is 13 inches, and the moment of the mass is ($978 \times 13 =$) 12,714 inch-pounds. The driving balance-weight is 243 pounds, of which the centre of gravity is 26 inches from the centre of the wheel, and the moment is 6318 inch-pounds. The trailing balance-weight is 147 pounds, having a radial distance of 27.75 inches, and the moment is ($147 \times 27.75 =$) 4080 pounds. The sum of these two moments is 10,398 inch-pounds, or 81 per cent of the moment of the entire reciprocating and revolving mass.

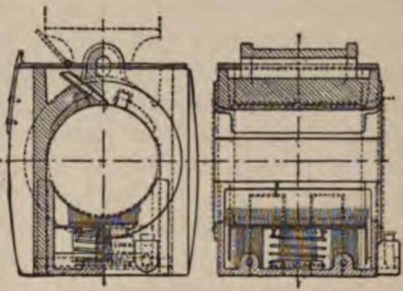
Balance-weights varying from 75 per cent to 100 per cent of this mass have been applied, with satisfactory results.

The bogie has two pairs of wheels 3 feet ½ inch in diameter, at 6-feet centres. It is allowed a lateral play of 2 inches—1 inch at each side of the central position. The frame consists of two 1-inch side-plates, 10¼ inches deep, 2 feet 8¼ inches apart; tied together by a large ribbed iron casting of 1¼-inch metal, about 10 inches deep, 2 feet 11 inches wide, and expanded at each end into flanges 4 feet 8 inches wide, by which it is bolted to the side-plates with seventeen ⅞-inch countersunk bolts and nuts at each side. The side-plates are also tied together with a 2-inch round stay-rod, nutted at both ends, at each end of the frame, through the axle-guards, outside the axle-boxes.

The casting is recessed at the centre to receive the socket for the pivot. The socket is of cast iron, 9 inches in diameter, formed with a rectangular disc on the upper side, 1½ inches thick, 21 inches by 19 inches, free to slide laterally between guides on the ribbed casting. The socket is bored out to 6 inches in diameter, to receive the pivot, which is $5^{15}/_{16}$ inches in diameter.

The pivot is developed upwards into a circular disc, 15 inches in diameter, which rests upon the socket-disc, and fits in and is confined by a circular flange on the socket-disc, within which it is free to revolve, bearing on a ¾-inch liner-plate of cast iron, of the same diameter. The pivot is finished with a rectangular head, 5 inches thick, fitted between and bolted to two 1-inch plates placed longitudinally, riveted with ⅞-inch rivets to the transverse horizontal 1-inch plates, already noticed, by which the main side frame-plates of the engine are bound together. The pivot-head is fastened between the longitudinal plates with eight 1¼-inch bolts and nuts. A 2½-inch safety-pin is passed centrally through the pivot, sustained by a cotter through the upper end and fitted with a flange-nut at the lower end.

The load is taken by two inverted side-springs, through the buckles, through each of which a 2½-inch pin is passed, fastened to the frame and the main ribbed casting with a nut. Each spring has a span of 3½ feet, with 2 inches of camber, loaded; and consists of eleven plates ½ inch thick, 5 inches wide. The ends are linked to the cradle with 1½-inch pins; the cradle consisting of two parallel 1-inch iron plates, 5 inches deep, 5¼ inches apart, made up with a cast-iron block with a semicircular bearing at each end, to take a bearing upon a semicircular seat formed on the top of the axle-box. The axle-boxes, figs. 878, are of gun-metal, with cast-iron keeps, held up with two ½-inch pins. The keeps are formed as troughs to hold oil for lubrication, which is fed upwards through wicks in each box into a pad, which is sustained by a helical spring in contact with the journal at the lower side. The brass is bored out to a diameter of 6 inches, and is 8⅞ inches long. The guiding surface of the box at each side is 6¹³/₁₆ inches wide, 11 inches deep, diagonally grooved for lubrication. The brass is lined with two strips of white metal near the crown.



Figs. 878.—"Great North" Locomotive: Bogie Axle-boxes. Scale 1/10th.

The guides for the axle-boxes are of cast iron, in pairs, each inner guide being fastened to the side frame-plates with seven ⅞-inch rivets; and each outer guide, with three rivets and also the 2-inch cross stay-rod, which ties the ends of the frame-plates. The lower ends of each pair of guides are bound to each other with two round cast-iron struts, and two 1-inch bolts and nuts.

The axles are 5½ inches in diameter in the body, and 6 inches at the journals, which are 9 inches long, and are 3 feet 8 inches apart on the same axle between the middles. They are 7 inches in diameter at the wheel seats, formed with a 7½-inch collar, which is let flush into the wheel-nave. They give a bearing 6 inches long in the wheel, and taper to 6¹⁵/₁₆ inches in diameter at the outer end, at the rate of 1 in 100. The wheels are 3 feet ½ inch in diameter over the tyre; 2 feet 7½ inches at the rim,

with naves 6 inches deep, 13 inches in diameter, having $3\frac{1}{2}$ inches of metal round the axle. There are ten spokes 3 inches by $1\frac{1}{8}$ inches near the rim, enlarged in section towards the nave; landed on the rim at a pitch of about $9\frac{3}{4}$ inches. The tyre is 5 inches wide, $2\frac{1}{2}$ inches thick, fastened with side-rings like those of the driving wheels. It is conical, with a taper at the rate of $3/16$ inch in 5 inches, or 1 in 27. Each wheel is fixed with one key, $1\frac{3}{8}$ inches by $\frac{3}{4}$ inch.

The boiler-shell is of Krupp iron. The barrel is $10\frac{1}{2}$ feet long, constructed telescopically, in three rings of plates, each ring one plate, diminishing in diameter from 4 feet 3 inches inside at the fire-box end, to 4 feet $\frac{5}{8}$ inch at the smoke-box end. The thickness of the rings is successively $\frac{1}{2}$ inch at the firebox-shell, $9/16$ inch, and $\frac{5}{8}$ inch at the smoke-box. The greater thickness at the smoke-box is designed to meet the stress of the frame where the attachments are made, through the smoke-box. The firebox-shell is 5 feet long, 3 feet $11\frac{1}{4}$ inches wide at the lower part, outside measure. The upper part of the shell is turned to a radius of 2 feet $6\frac{3}{4}$ inches inside, concentrically with the barrel. It is of $\frac{1}{2}$-inch plates, except the front plate, which is $\frac{5}{8}$ inch thick. This plate is flanged with a radius of $1\frac{3}{8}$ inches inside, to join the barrel with a double-riveted joint. The back plate is flanged with a 3-inch radius, to join the covering-plate, with single-riveting. The barrel is joined to the smoke-box tube-plate, $\frac{3}{4}$ inch thick, with an angle-iron ring $4\frac{1}{2}$ inches on the barrel, $\frac{3}{4}$ inch thick, double-riveted; and $3\frac{1}{4}$ inches on the tube-plate, $\frac{7}{8}$ inch thick, single-riveted. The intermediate circular seams of the barrel are single-riveted. The longitudinal seams are double-riveted, with a welted butt-joint. The riveting is made with $13/16$-inch rivets, at $1\frac{7}{8}$ inches of pitch, for both single-riveting and double-riveting; lapped $2\frac{1}{2}$ inches for single seams; and $3\frac{1}{2}$ inches for double seams, except for welts, which are lapped $3\frac{3}{4}$ inches. Rivets are partially countersunk into each lap, and are finished with cup-heads. The rivets uniting the tube-plate to the angle-iron are formed with a deep countersink at each side of the joint.

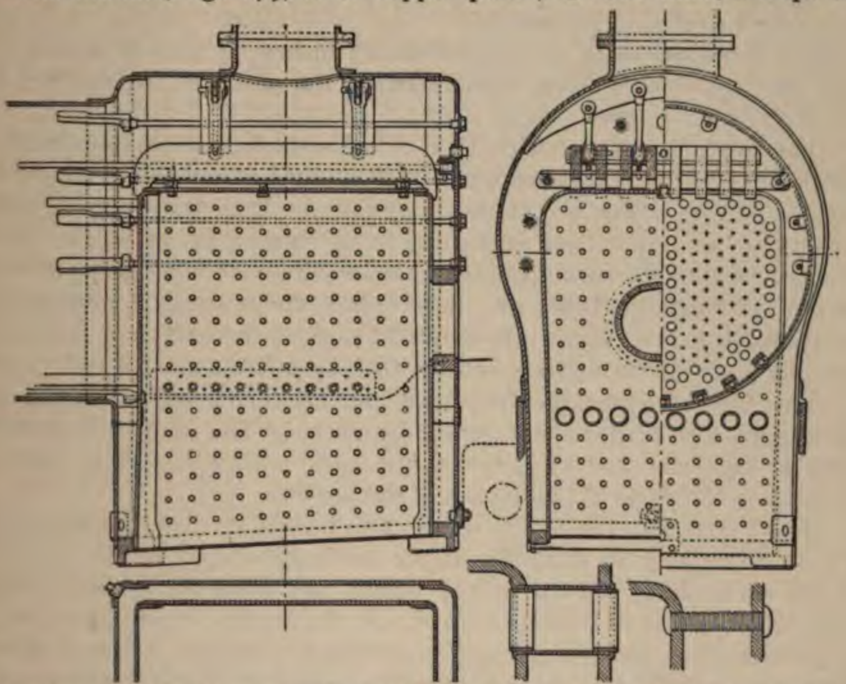
The steam-dome, mounted on the top of the firebox-shell, is of $\frac{5}{8}$-inch metal, 18 inches in diameter inside, 2 feet 2 inches high. It consists of a seat single-riveted to the boiler, flanged to join the upper part, which falls in at the top and is flanged to seat the safety-valves. The opening into the firebox-shell is 19 inches in diameter.

The smoke-box is 2 feet $8^{11}/_{16}$ inches long inside, turned to a radius of 2 feet $5^{1}/_{16}$ inches at the upper part. The tube-plate is flanged entirely round its border, and is riveted to the side frame-plates and to the horizontal transverse plate, over the bogie, which forms a bottom for the smoke-box. The covering-plate, $5/16$ inch thick, is joined with welts to the longitudinal frame-plates. It is riveted to the tube-plate with $\frac{3}{4}$-inch rivets, countersunk at the outside, and to the front plate, $7/16$ inch thick, with $2\frac{1}{2}$-inch angle-iron and $\frac{5}{8}$-inch rivets, at $2\frac{1}{2}$ inches of pitch. The chimney is of $3/16$-inch plate-iron, the [illegible] nding 12 feet 8 inches above the level of the rails. The b[illegible] wrought iron; the top

is of copper. It is lined to a diameter of 15¾ inches inside at the lower end, tapering to 14⅜ inches at the top.

The firebox-shell is supported by side angle-irons on the main frame-plates, on which it is free to slide by expansion and contraction. It is held centrally between the frame-plates by a joggle connection at the back plate, under the fire-door, in which a joggle of wrought iron riveted to the shell enters a corresponding recess in a wrought-iron piece let into and fastened to the back of the cast-iron platform. Thus the exact alignment of the boiler and the frame is secured, whilst there is freedom for longitudinal expansion.

The fire-box, figs. 879, is of copper plates, ½ inch thick, except the



Figs. 879.—"Great North" Locomotive: Fire-box and Shell, showing Smoke-preventing Design. Scale 1/32d.

tube-plate, which tapers in thickness from ½ inch at the lower edge to ⅞ inch at the tubes. The covering-plate, in one piece, is single-riveted to the back and front plates. The fire-box is 4 feet 3⅞ inches long inside at the base, 3 feet 3¼ inches wide, with 3-inch water-spaces, which expand upwards, with the taper of the fire-box, to 4 inches at the back, and 3½ inches at the front. The sides lead into the top with a curve of 8-inch radius. The fire-box is stayed to the shell with ⅞-inch copper stay-bolts, at 4-inch pitch, screwed for their whole length, 11 threads per inch, and headed over at each end; and is joined at the bottom with a solid wrought-iron foundation ring, 2½ inches by 3 inches, and single-riveting. The fire-box is also stayed with seven wrought-iron palm-stays riveted to the lower part of the barrel, half-way along the first ring-plate, into the ends of which

screws passed through the tube-plate are screwed. The roof of the fire-box is stayed with four pairs of wrought-iron stay-bars, each 6 inches deep, 2 inches thick, $1\frac{3}{4}$ inches clear of the roof, but fitted to bear on the front and back plates, and fastened to the roof-plate with ten intermediate 1-inch screws, entered from below the plate, and thimbles between the plate and the stays to take the stress. The stays are $4\frac{3}{8}$ inches apart between centres, and each pair is linked with two links and $1\frac{1}{8}$-inch pins to two transverse T angle-irons, 5 inches by $3\frac{1}{2}$ inches, riveted to the shell. These irons are fixed close to the opening made into the dome, and strengthen the shell at that place. The back plate of the firebox-shell is also stayed to the barrel, with eight $1\frac{1}{8}$-inch rods, screwed into eyes on palm-stays riveted to the barrel.

The fire-doorway is 15 inches wide, 13 inches high, made with a solid iron ring, $2\frac{3}{4}$ inches thick, fitted between the plates of the fire-box and the shell, single-riveted.

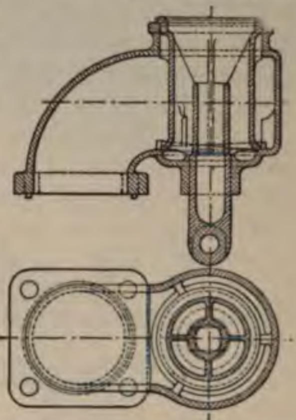
The fire-box is fitted with D. K. Clark's smoke-prevention apparatus, consisting of a row of eight copper air-tubes, 3 inches in diameter externally, pitched at $4\frac{7}{8}$ inches, across the front and the back water-spaces, with a steam-pipe ranged outside each row, from which a jet of steam can be discharged through each opening, when required for stimulating the air-currents through the tubes into the fire-box, above the fuel, amongst the combustible gases. Each tube is turned over at the ends, and is fastened into the plates of the fire-box and the shell by a ferule at each end.

The fire-bar frame is pivoted on the back end, and is raised and lowered by a lever movement worked by a screw. The ash-pan is 12 inches deep at the front and 15 inches at the back, with a damper at each end adapted to the slope of the bottom of the fire-box.

There are 206 brass flue-tubes, $1\frac{3}{4}$ inches in diameter externally, No. 12 wire-gauge in thickness at the fire-box, tapered to No. 14 gauge at the smoke-box; pitched at $2\frac{1}{2}$ inches, and therefore $\frac{3}{4}$ inch clear of each other; arranged in vertical rows. At the smoke-box end, for a length of 3 inches, they are enlarged to $1\frac{13}{16}$ inches in diameter; and at both ends the tubes are a tight fit in the tube-plates, over which they are turned at the ends. They are fastened with ferules $1\frac{3}{16}$ inches long into the fire-box tube-plate, which project $\frac{1}{8}$ inch from the ends of the tubes, to allow of being driven up when needful. The flue-tubes are not horizontal; they incline upwards towards the smoke-box, where they are 1 inch higher than at the fire-box.

The horizontal steam-pipe within the boiler is of $\frac{3}{16}$-inch copper, $4\frac{1}{2}$ inches in diameter, taking steam from the upper part of the dome. The upright portion in the dome is of cast iron, $\frac{1}{2}$ inch thick, and it supports a brass double-beat valve, $5\frac{1}{2}$ inches in diameter, which is opened by shifting it vertically in the case, figs. 880. The [illegible] by
a shallow ledge, the upper edge of which consis[illegible]
winding each half-way round the circle, w[illegible]
formation, the opening for steam, which

the supply of steam are gradually increased as the valve is lifted to a level of ⅜ inch above the seat. When the valve is raised above this level, steam is freely admitted all round the lower valve. The upper valve is formed with a cylindrical extension of ½ inch downwards, which exactly fits and slides in the case; and it is only when the valve is elevated at least ½ inch that steam can enter that way, in addition to the steam by the lower valve. By this combination steam is admitted into the steam-pipe in a gradual manner, as the valve is raised:—first gradually, by the lower valve, and afterwards, as the valve continues to be lifted, by the upper valve as well as by the lower valve.

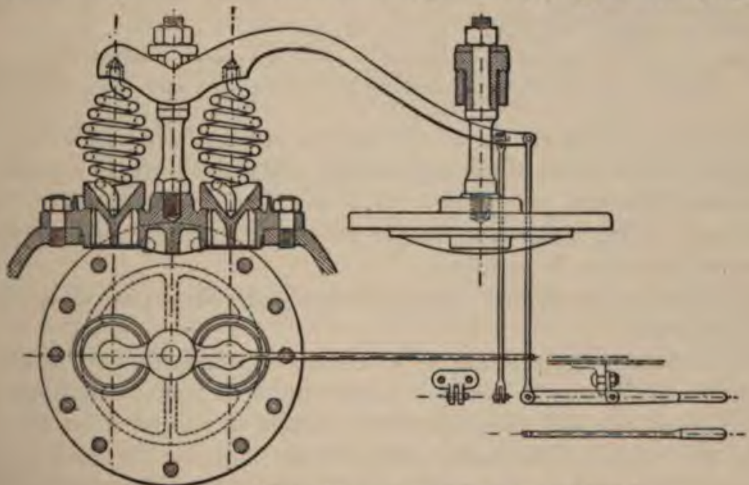


Figs. 880.—"Great North" Locomotive: Regulator-valve. Scale 1/10th.

The regulator-valve is moved by a link from a short arm, 1⅞ inches long, on the shaft, which has a bearing in a socket formed in the base of the cast-iron pipe, and passes through a stuffing-box to the back of the fire-box, where it is fitted with a double hand-lever of two 18-inch arms.

The steam-pipe is formed with a brass conical end to join the cast-iron pipe; and a brass flange at the other end, by which it is bolted to a cast-iron double-branch steam-pipe in the smoke-box, from which steam is conducted through two branch copper pipes, 4 inches in diameter, No. 7 wire-gauge in thickness, to the cylinders at the right and the left.

There is a pair of direct-action safety-valves, of gun-metal, figs. 881,



Figs. 881.—"Great North" Locomotive: Safety-valves. Scale 1/10th.

in a gun-metal seating, bolted to the top of the steam-dome. The opening the dome is 9⅝ inches in diameter, and the seat is fastened to the dome fourteen ¾-inch stud-bolts and nuts. The seats of the valves are zontal, the valves lapping 3/16 inch over the seat. Each valve is guided

by four leaves in the cylindrical seat, and is formed as a hollow cone on the upper side, to give a bearing to the lower end of the spring, below the level of the seat of the valve: so inducing stable equilibrium. Each spring is of ⅝-inch round steel, coiled as a double spiral, of maximum diameter at the middle of its height, tapering upwards and downwards to two points, which take their bearings, one in the valve, the other in a hollow bearing formed in a lever above. The two valves with their springs are placed at 6¼-inch centres, and the fulcrum of the lever is midway between them. The fulcrum is a gun-metal casting, formed with two 1-inch round studs, on which the lever takes a bearing. The lever is of wrought iron,

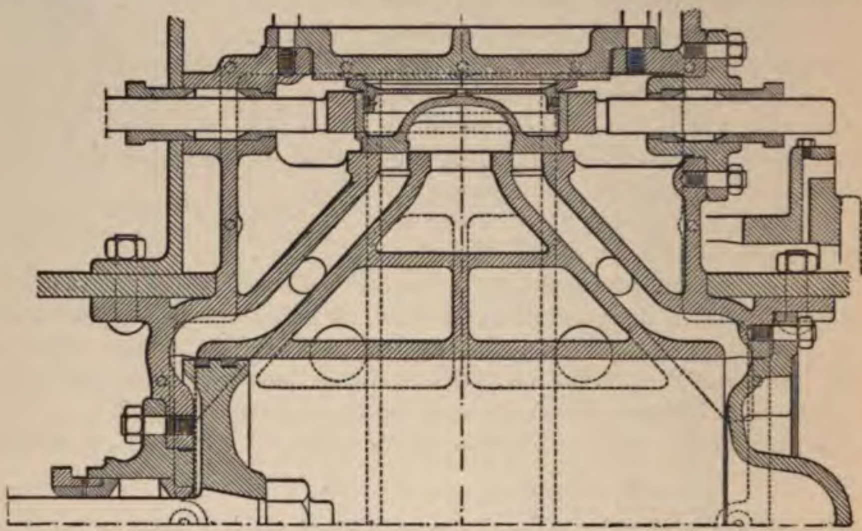


Fig. 882.—"Great North" Locomotive: Cylinder, Piston, and Slide-valve. Scale 1/10th.

19 inches long, from the fulcrum; and is moved, when necessary, by a hand-lever within reach of the engineman, connected to it by a small rod.

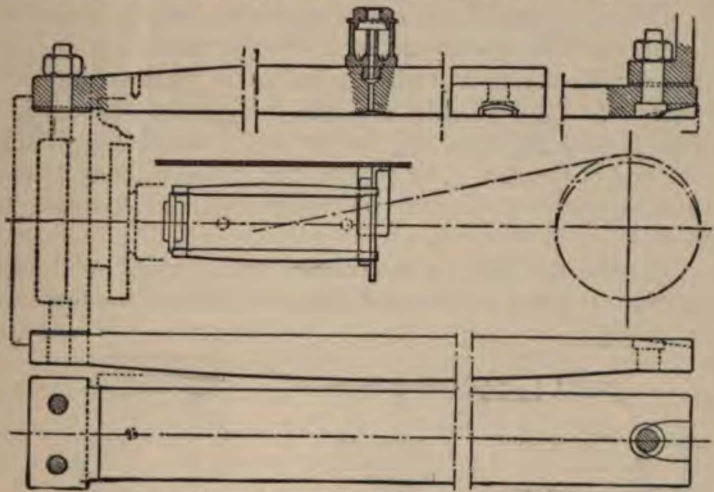
The safety-valves are loaded to a working pressure of 150 lbs. per square inch. The boiler was tested in steam to a pressure of 160 lbs., and by water to 200 lbs. pressure.

The boiler is coated with silicate cotton, and yellow-pine clothing cased with sheet iron.

The cylinders, fig. 882, are 17½ inches in diameter, with a stroke of 26 inches. They are 6 feet 2½ inches apart between centre-lines, and they overhang the side frame-plates 12 inches, measured from the centre-line to the plate. The outer side frame-plate is 8½ inches beyond the centre-line; and as the cylinder is bolted to both plates, it not only receives but also gives solid support. Besides, the cylinders and the frame-plates are solidly bound together by the massive 1-inch plate, already noticed, inserted horizontally between the cylinders and the plates, over the bogie connections.

The cylinders are of 1-inch metal, except at the steam passages, where

it is ⅞ inch thick. The outer cover is of ¾-inch metal; so also are the steam passages, except at the top and bottom, where they are ⅞ inch thick. The valve-chest is of 1-inch metal at the top and bottom, and ⅞-inch metal at the ends; the cover is ⅞ inch thick. The cylinder is fastened to the main frame-plate with 1¼-inch flanges, and 1⅛-inch bolts and nuts—five through the top flange, and four through each end flange, or thirteen in all—and to the outer frame-plate with 1-inch flanges and six 1-inch countersunk bolts and nuts. The outer end flange of the cylinder is 1⅜ inches thick, to which the cylinder-cover is bolted with a 1⅛-inch flange, and thirteen ⅞-inch stud-bolts and nuts, pitched at about



Figs. 883.—"Great North" Locomotive: Guide-bars. Scale 1/10th.

4⅞ inches. The inner flange is 1 7/16 inches thick, having an opening 8 inches in diameter, closed by a cover 1¼ inches thick, with four 1-inch stud-bolts and nuts. The opening of the valve-chest is 16 inches by 13½ inches, and is closed with sixteen ⅞-inch stud-bolts and nuts, pitched at 4 inches and 4½ inches. The end lid of the valve-chest, 1⅛ inches thick, is fastened with fourteen ⅞-inch stud-bolts and nuts, at 3½ inches of pitch.

The steam-ports are 1½ inches by 13½ inches, and the exhaust-port is 3 inches by 13½ inches, rounded at the ends; giving 20¼ square inches and 40½ square inches of area respectively, or about 1/12th and ⅙th of the area of the cylinder. The bars between the ports are 1¼ inches thick.

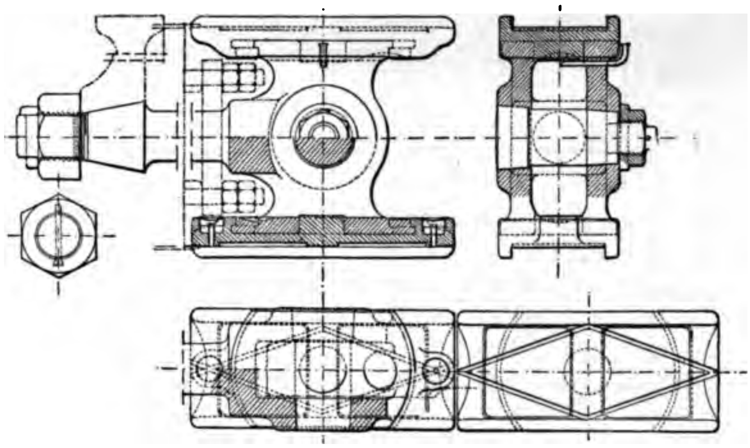
The steam is exhausted from each cylinder through an exit opening 4 inches by 7 inches, joined to the exhaust-pipe. The two exhaust-pipes are united at the upper part, forming one pipe, finished with a 4½-inch brass nozzle, terminating at a level 2 inches above the uppermost flue-tubes and 25½ inches below the entrance to the liner in the chimney.

Each cylinder is fitted with one pair of guide-bars, of Krupp crucible steel, figs. 883, one above and the other below the crosshead; 11¾ inches apart, 5 inches wide, 1⅝ inches thick at the ends, swelled to 2½ inches at

the centre; fastened with two 1⅛-inch stud-bolts and nuts to the cylinder-cover, and one 1⅛-inch bolt and nut to the motion-plate, with ⅛-inch brass liners. The total length of the bars is 3 feet 7¼ inches. A brass oil-cup, 1⅞ inches in inside diameter, is screwed into the upper bar at mid-length.

The piston, fig. 882, is of cast iron, in one piece, 3½ inches wide at the rim and at the nave, and of the minimum thickness 1⅝ inches near the rim, thickened up to 3½ inches at the nave. The piston is fitted with two packing-rings of cast iron—cylinder metal—13/16 inch wide by ⅜ inch thick, let into two grooves. They are turned to a diameter ⅜ inch larger than the cylinder; a piece is cut out of each ring, and the rings are sprung into their places. The piston-rod is of crucible steel, 2¾ inches in diameter, formed with a conical end, 3¾ inches in diameter, tapered, at the rate of 1 in 2½, to 2½ inches, let into and through the piston, and fastened with a brass nut on the end, 2¼ inches thick, secured by a split cotter through the end of the rod. The stuffing-box gland is made with an inside annular wearing-piece, which may be renewed without renewing the body of the gland.

The crosshead, figs. 884, is of crucible steel, forked, solid-forged with the piston-rod. It has a 3-inch steel gudgeon, let into the forks with coni-

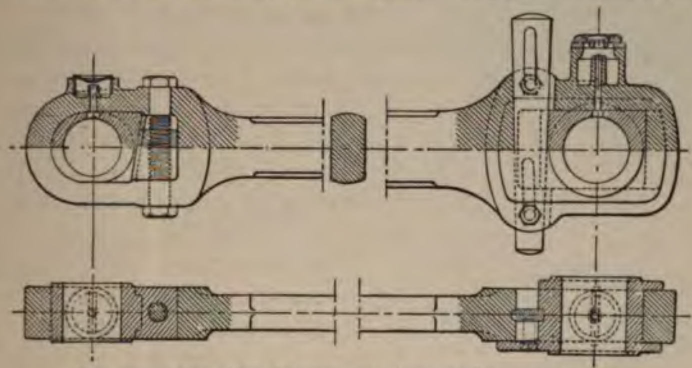


Figs. 884.—"Great North" Locomotive: Crosshead. Scale 1/10th.

cally formed seats, fastened with a nut at the outside. The journal is 3 inches long. The guides are 14 inches long and 5 inches wide on the guide-bars, one above and one below the crosshead, to which they are fastened by keys.

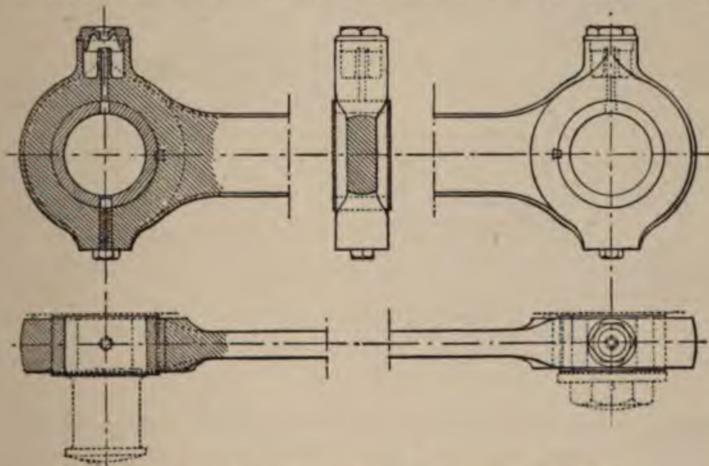
The connecting-rod, figs. 885, is of wrought iron, one solid forging, 6 feet 1½ inches long between centres, or 5.65 times the length of the crank. It is 1¾ inches thick in the body, by 3 inches deep at the crosshead end, expanding to 4 inches deep at the crank end. At the crosshead end the bearing is 3 inches in diameter, 2 15/16 inches long. The brasses are of phosphor-bronze, the outer brass being ⅝ inch thick at the bend, formed

circularly to minimize the space occupied within the crosshead, and maximize the length of the rod. The inner brass is $1^1/_{16}$ inches thick, flat and inclined to take the action of a steel wedge, adjustable vertically by means of two 1-inch screws, one entered into the wedge from above, the other



Figs. 885.—"Great North" Locomotive: Connecting-rod. Scale 1/10th.

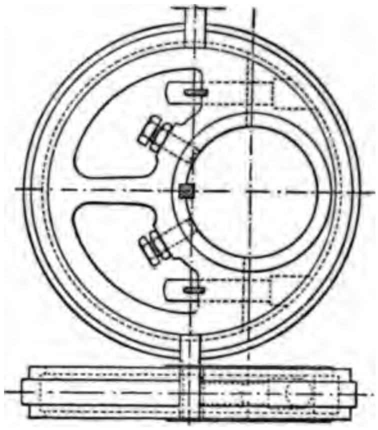
from below. The end is 2¾ inches thick, 1⅛ inches wide above and below the brasses, increased to $1^7/_{16}$ inches at the adjusting screws. At the crank end the bearing is 3½ inches in diameter, $3^{15}/_{16}$ inches long. The brasses are square, front and back; the outer brass is ⅞ inch thick at the end, and the inner brass is 1¼ inches thick at the back. The brasses are lapped with ½-inch flanges on the faces of the end, which is 2¾ inches



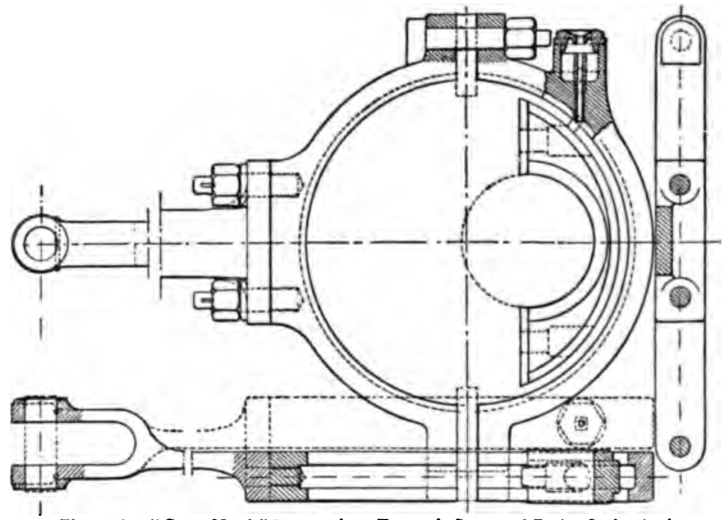
Figs. 886.—"Great North" Locomotive: Coupling-rods. Scale 1/10th.

thick. They are tightened with an ordinary cotter of steel, 12¼ inches long, $^9/_{16}$ inch thick, tapered from 2 inches to 1⅜ inches wide, at the rate of about 1 in 19; secured with two ⅝-inch steel set-screws. The end is 1¼ inches thick above and below the brasses, rounded to 1⅝ inches thick at the head, in the centre-line of the rod. An oil-cup is formed on each end. The ends are case-hardened.

The coupling-rods, figs. 886, are 8 feet long between centres, bushed with phosphor-bronze bearings, 4½ inches in diameter, 2 15/16 inches long. The bushes are circular, each in one piece, ⅝ inch thick, fastened in place with a dovetail steel key, ⅝ inch by 7/16 inch, and secured with a ¾-inch screw through the eye of the rod, from below, the end of which is lodged in a hole in the bush. The eye at each end of the rod is 2¾ inches thick, 9 inches in diameter, making 1⅝ inches of metal round the bush, with an oil-cup forged on. The body of the rod is of uniform section, 1⅜ inches thick, 4¼ inches deep.


Figs. 887.—"Great North" Locomotive: Eccentrics. Scale 1/10th.

The slide-valve of each cylinder, fig. 882, is of gun-metal, having 1 1/16 inches of lap at each end. The travel in full gear is about 4½ inches, the lead is ⅛ inch, and steam is cut off at 76½ per cent. It is balanced on Thomas Adams' system, formed with a circular recess at the back, which is occupied by a cast-iron piston having one packing-ring, in one piece with a flat backing, which slides on the inner side of the valve-chest cover. The steam is in this way prevented for the most part from pressing on the back of the valve. The face of the valve is 16 inches by 10⅝ inches, making an area of 170 square inches,


Figs. 888.—"Great North" Locomotive: Eccentric Strap and Rod. Scale 1/10th.

against the area of the balance-piston, 10¼ inches in diameter, 82.5 square inches. The area of the balance-piston is equal to 1.10 times the area of the cavity of the valve: a proportion which is said to answer well.[1]

[1] The Adams valve has been used on other railways.

The valve-spindle is of wrought iron 1¾ inches in diameter, working through a stuffing-box at each end of the valve-chest.

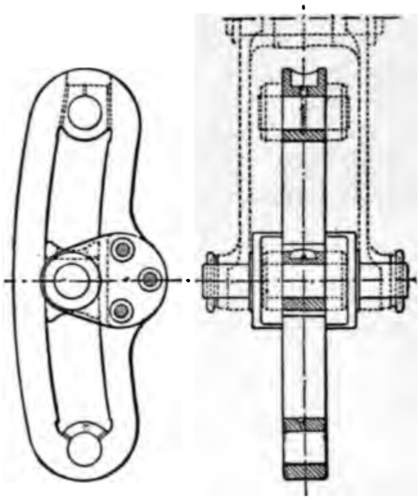
The valve-motion is the ordinary shifting link-motion, the expansion-link being lifted by the middle. The eccentric-rods, figs. 888, are each 5 feet 1 inch in length; the eccentrics, figs. 887, have each a throw of 6½ inches. They are set on the shaft at 105° for the forward eccentric, 106° for the backward eccentric; the expansion-link, figs. 889, is 18 inches long between its end centres to which the rods are pinned, curved to a radius of 5 feet 1 inch, the length of the rods; the lifting-link is 14 inches long, pinned to a 15-inch arm on the reversing shaft. The following tablet shows the distribution for four notches of the sector:—

Distribution:—Forward Gear.

Notch.	Travel of Valve.	Lead.		Port Opens.		Cut-off.		Exhaust.	
		B.	F.	B.	F.	B.	F.	B.	F.
	inches.	inch.	inch.	inch.	inch.	per cent.	per cent.	per cent.	per cent.
Full Gear.	4 7/16 1/32	3/32	5/32	13/16 1/32	1⅛	74½	78½	91½	94
Third......	3 13/16	5/32	7/32	⅞	13/16	64	67	86½	90
Second....	3¼	3/16 *f.*	¼ *f.*	9/16	9/16	48	50	79	83
First.......	2 13/16 1/32	5/16	5/16	5/16 1/32	⅜	27½	28½	67	71
Backward Gear.									
Full Gear.	4½ 1/32	3/32	5/32	1¼ 1/32	1⅛	75	79	92	94
Third......	3 13/16	5/32	7/32	⅞	13/16	63½	66½	86½	90
Second....	3¼	3/16 1/32	¼ 1/32	9/16	9/16	47	49	79	82½
First.......	2 13/16 *f.*	¼	5/16	5/16 *f.*	⅜	25½	27½	65½	69

The eccentrics, figs. 887, are each in two parts to join round the axle: the smaller of wrought iron, the larger of cast iron, fastened with 1⅛-inch cotter-bolts. The body of the eccentric is 16 inches in diameter, 2⅝ inches wide, notched out at each side. The eccentric-strap, fig. 888, is of wrought iron, 2⅝ inches wide, indented ⅜ inch in the middle to receive a liner of cast iron, ⅞ inch thick; having 1 inch of minimum thickness. The strap is in halves, joined with two 1⅛-inch bolts and nuts. On one half an oil-cup is formed; the other half is made up with a flat face, 8½ inches by 2⅝ inches, to which the end of the eccentric-rod is fastened, with a palm 1¼ inches thick, and two 1⅛-inch stud-bolts, washers and nuts, with a safety-cotter. The eccentric-rod is ⅞ inch thick, 3½ inches wide at the eccentric end, tapered to a width of 2¼ inches at the link end. It is forked to take the link with a 1¾-inch pin. The expansion-link, figs. 889, is 2¼ inches thick; the slot is 2¾ inches wide, in which the movable block or die is 4⅛ inches long. Two stud-brackets are riveted on the sides of the link, at the centre, having 1¾-inch stud-pins for suspension. The transverse reversing-shaft is 3¼ inches in diameter in the body; 3 inches at each end, with journals 3 inches long, carried in cast-iron bearings bolted

to the main frame-plates. The link and its accessories are balanced by two cast-iron counterweights, 9 inches square, 6 inches thick, bolted to arms on the reversing-shaft. The reversing-rod is 12 feet 10½ inches long, having 1½-inch connecting-pins at the ends. It is ¾ inch thick, 2¼ inches deep at each end, expanded to 4 inches in depth at the middle. The reversing-lever is ¾ inch thick, 4 feet 7 inches long, the fulcrum being at the lower end, and the reversing-rod being pinned to the lever at a distance of 15 inches above the fulcrum. It is made with a spring detent to notch into the sector, which has a radius of 27 inches. A treadle is solid with the reversing-lever, from the same fulcrum, in order that the manual power may be aided by the weight of the body.



Figs. 889.—"Great North" Locomotive: Expansion-link. Scale 1/10th.

A sand-box is fixed to the splasher-cover of each driving-wheel. A steam-break, actuated by means of a 9½-inch single-acting steam-cylinder, is applicable to each of the four coupled wheels, through arms on a transverse shaft, 14 inches and 7 inches long—as 2 to 1—and hangers, to the lower ends of which the pull is applied, making a leverage of 2 to 1 on the cast-iron break-blocks. Thus the leverage of the piston on the break blocks is $(2 \times 2 =)$ 4 to 1.

Detail Weights.	tons.	cwts.	qrs.	lbs.	For One Locomotive. tons.	cwts.	qrs.	lbs.
Boiler-shell	3	6	3	0				
Boiler, complete, with fire-box, flue-tubes, and stays	8	3	2	0	8	3	2	0
1 pair of cylinders, with slide-valves and buckles	1	18	0	16	1	18	0	16
1 piston, rod, crosshead with pin and slide-blocks, complete	0	3	0	9	0	6	0	18
1 connecting-rod	0	1	3	5	0	3	2	10
1 coupling-rod	0	2	0	1	0	4	0	2
1 pair of driving-wheels, axle, and crank-pins	2	18	0	8	2	18	0	8
1 pair of trailing do. do. do.	2	15	2	18	2	15	2	18
1 driving axle-box	0	2	0	8	0	4	0	16
1 trailing do.	0	2	0	8	0	4	0	16
1 bogie do.	0	0	3	23	0	3	3	8
1 pair bogie wheels and axle	1	0	3	20	2	1	3	12
Bogie, complete	4	12	0	0				
Framing, &c.					16	11	3	16
Total weight of locomotive, empty...					35	15	0	0

TENDER.

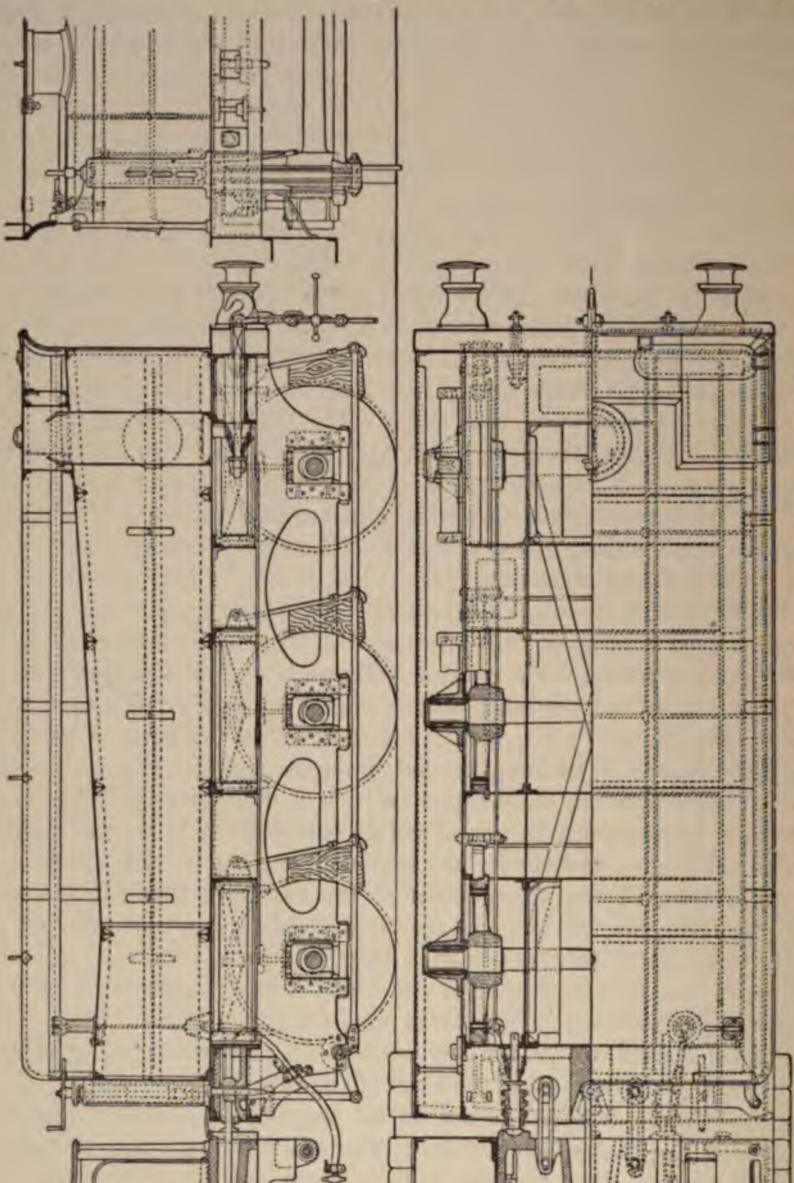
The tender, figs. 890, is constructed to hold 1950 gallons, or 8.70 tons, or 312 cubic feet of water; and has capacity for 160 cubic feet of fuel, or about 3½ tons of coal. It is on three axles and six wheels 3 feet 7½ inches in diameter, equally spaced on a wheel-base of 11 feet. The weight empty, as already stated, is 15 tons; the weight fully loaded with fuel and water, is, according to the above estimation, $(8.7+3.5=)$ 12.2 tons more, or, for a round number, 12 tons, making a total maximum of 27 tons, averaging 9 tons per pair of wheels.

The frame is 17 feet ⅝ inch long at the outside, 7 feet 9 inches wide; and it stands 4 feet 1 inch high above the level of the rails. It is composed of two main longitudinal ⅞-inch frame-plates, 33⅜ inches deep, to which the axlebox-guides are fastened, and two ½-inch outer longitudinal plates, made 8 inches deep, for the sake of uniformity with the frame of the engine; with eight transverse plates, united with angle-irons. It is stiffened by two diagonal bars 4 inches by ½ inch thick. The axles are of steel, 5⅝ inches in diameter at the middle, enlarged to 6¼ inches at the backs of the wheel-naves; 7 inches in the wheel, tapered 1 in 100, to 6 29/32 inches at the outer end of the nave, with outside journals, 5 inches in diameter, 10 inches long, at 6-feet-3-inch mid-lengths on the axle. The wheel-nave is 9 inches wide, 14½ inches in diameter, making 3¾ inches of metal round the axle. The tyres are 5¼ inches wide, 3 inches thick. The springs, one over each axle-box, are 3¼ feet in span, each composed of nine ⅜-inch plates and one ½-inch plate, 5 inches wide, bearing through a 1½-inch pin on the axle-box. The tender is connected to the engine at a fixed distance, with a 2½-inch draw-bar and a 2¼-inch pin, and bears on the back of the engine platform by means of two cup-headed spring buffers, 3 feet 4 inches apart, lodged in corresponding cup-shaped recesses in the platform. The buffer-rods take a bearing on a 25-pound volute spring to each, by the resistance of which the engine and tender are taut with respect to each other; at the same time that, by the engagement of the cup-form buffer-heads in the engine platform, the two vehicles are maintained in proper alignment.

The tank is 16 feet 4½ inches long, 7 feet 2 inches wide, outside measure; 3 feet 2 inches high at the back, sloping downwards to 2 feet 6½ inches at the front. The sides are extended upwards, and form a coping to a height of 4 feet 1½ inches, making stowage capacity for fuel: standing 8¼ feet above the level of the rails.

A screw-break is fitted to act on all the wheels, a wood block being applicable at the back of each wheel. The screw is 2⅜ inches in diameter, of ½-inch pitch. It is vertical, and pulls an arm 13 inches long on a transverse shaft, through which, by the medium of short arms, 4 inches long, the force is transmitted by rods to the lower ends of the break-hangers. The force applied by hand to the hand-lever of 9 inches radius, is multiplied as follows:—One turn of the handle through a circle of 9-inch radius, or 56.5 inches, moves the nut through ½ inch on the screw,

in the ratio of 113 to 1. By the arms on the transverse shaft the movement is reduced as 14 to 4, or as $3\frac{1}{2}$ to 1; and the leverage of the hanger on the middle of the block is as 31 inches to 23 inches, or as 1.35 to 1.



Figs. 890.—"Great North" Locomotive: Tender. Scale 1/50th.

Combining these ratios, the resultant ratio is as $(113 \times 3\frac{1}{2} \times 1.35 =)$ 534 to 1. The gross weight of the tender is, as already stated, 27 tons; and, taking the maximum adhesive force on the rails at one-fifth of the weight, it is $(27 \times 2240 \div 5 =)$ 12,096 pounds; ([illegible] 34, the leverage =)

22.6 pounds the required net stress at the handle to skid the wheels. In addition, the frictional resistance is to be overcome.

A buffer-beam, buffers, drawhook and spring, are applied at the back of the tender, as to the front of the locomotive, with a screw-coupling.

The price of the engine was £1775, or £49, 13*s.* per ton of weight; that of the tender was £400, or £26, 13*s.* per ton; and the price of the engine and tender together was £2175, or £43 per ton.

CHAPTER LXIV.—SINGLE-WHEEL EXPRESS PASSENGER LOCOMOTIVES.

DESIGNED AND CONSTRUCTED BY MR. PATRICK STIRLING, FOR THE GREAT NORTHERN RAILWAY.

I. OUTSIDE-CYLINDER LOCOMOTIVE.

PLATE XV.

(Cylinder 18 inches in diameter; stroke 28 inches; wheels 8 feet 1 inch in diameter; gauge of way 4 feet 8½ inches.)

The class of single-wheel locomotive for express traffic, third figure on Plate XV., and figs. 891 and 892, annexed, designed and first constructed by Mr. Stirling in 1869, is one of the most recent developments of the single-wheel engine; and there are now upwards of forty such engines running the heavy and high-speed express trains. It is placed on eight wheels—four in a leading bogie, one pair of driving wheels, and a pair of carrying wheels behind. The cylinders are horizontal, placed outside the longitudinal frame-plates, between the wheels of the bogie, at each side. The axles are constructed for inside bearings.

The driving wheels are 8 feet 1 inch in diameter. The trailing wheels are 4 feet 1 inch in diameter. The bogie wheels are 3 feet 11 inches in diameter, and the bogie-axles are placed at a distance apart of 6½ feet between the centre-lines. The bogie is not pivoted centrally between the axles; the pivot is, on the contrary, placed 3½ feet behind the leading axle of the bogie, and is only 3 feet in front of the hind bogie-axle. The effect of this unequal distribution is to apportion the load on the bogie, so that the less weight is on the leading bogie-axle and the greater weight is on the hind bogie-axle—so graduating the load up to the maximum weight on the driving wheels. In this way the weight of the engine, in working order, 45¼ tons, is so distributed:—

		Tons.	Cwts.
Leading bogie wheels, ...	17 tons 11 cwts.	8	2
Hind do.		9	9
Driving wheels, ...		17	0
Trailing do.		10	12
		45	3

As Mr. Stirling intelligibly puts it, "The bogie in front carries a compara-

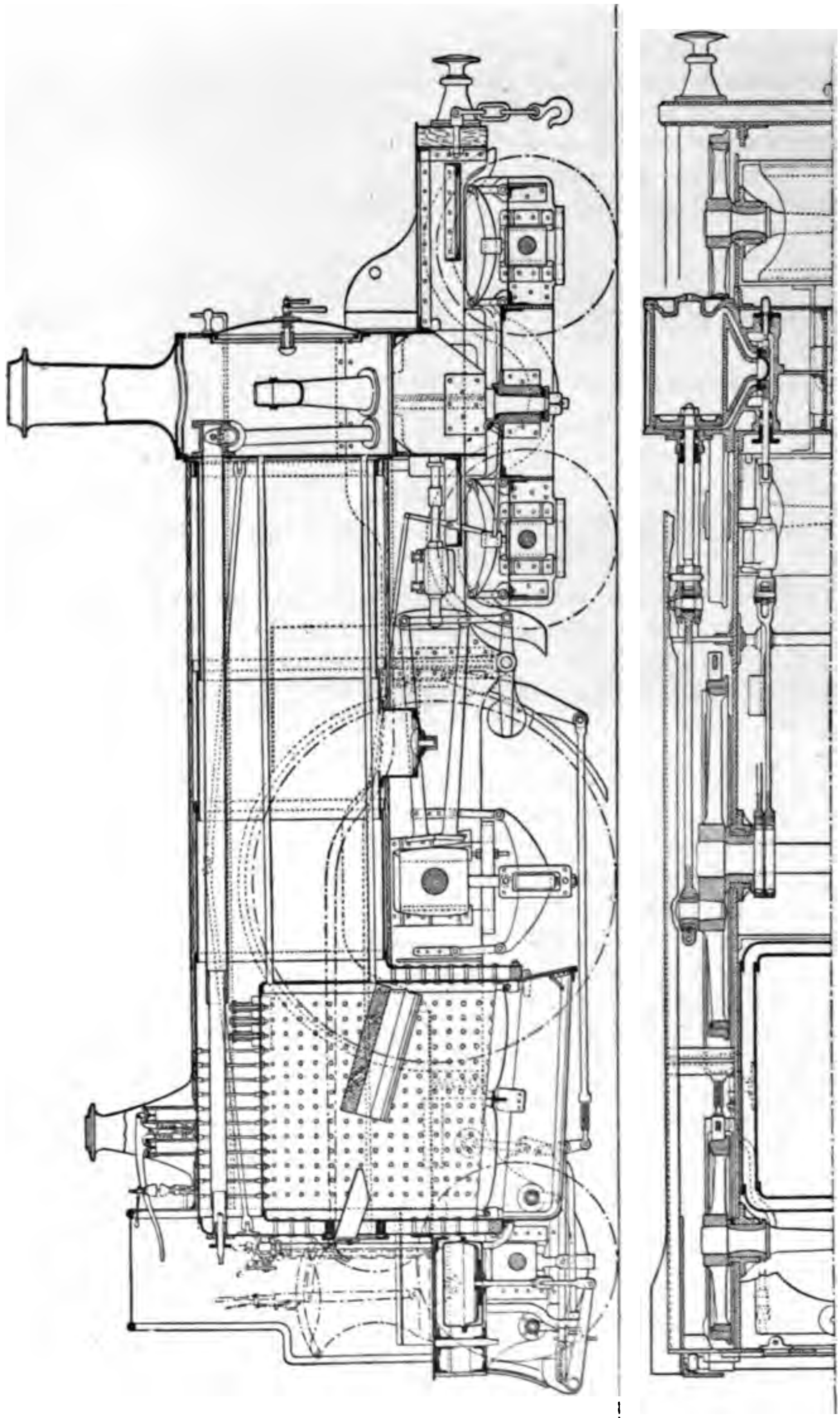


Fig. 891.—Great Northern Railway: Single-wheel Outside-cylinder Express Passenger Locomotive, by Mr. P Stirling. Longitudinal Section. Scale 1/30th.

tively light weight on each wheel, but quite sufficient to solidify the road before the driving wheels come on the rails, and thereby put the rails in the best position to carry the weight of the large wheels." It may be added that the load at the trailing wheels also has its importance: it holds down the rails behind the drivers, as the load on the bogie wheels does in front. Thus a long and comparatively steady bed is made for the engine. "The engine," Mr. Stirling adds, "seems to have plenty of adhesion for the size and power of the cylinders, and does not slip more than coupled engines under similar circumstances; and, with a slight application of dry sand, slipping is entirely prevented." The weight, 17 tons, on the pair of driving wheels would be excessive, and would no doubt overtask the power of resistance of rails of iron. But the rails on the Great Northern Railway, as on other leading lines, are of steel, and, as Sir John Fowler said "Mr. Stirling, with great judgment, has taken advantage of this altered condition of things, and has put 15 tons (now 17 tons) on the single driving wheels of the Great Northern engines."[1] The weight on the driving wheels, it is stated, does not appear to be objectionably heavy. These large engines are the least fatiguing to the road.

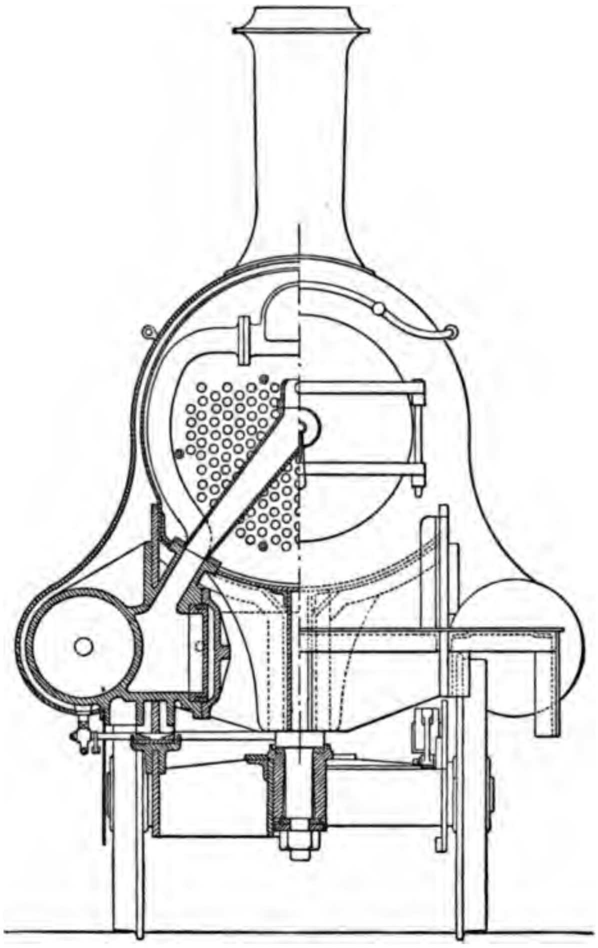


Fig. 892.—Stirling's Outside-cylinder Express Locomotive: End Elevation and Section at Smoke-box and Cylinders. Scale 1/32d.

The bogie-axles, it has been said, are 6½ feet apart; the distance from the pivot of the bogie to the driving axle is 10 feet 9 inches, and from the driving axle to the trailing axle, 8 feet 8 inches, making a total wheel-base of (3 feet 6 inches + 10 feet 9 inches + 8 feet 8 inches =) 22 feet 11 inches.

[1] Discussion on Mr. John Robinson's paper, in the *Proceedings of the Institution of Civil Engineers*, 1873-74; vol. xxxvii. page 23.

Reckoned from the pivot of the bogie the wheel-base is 19 feet 5 inches in length.

There is another advantage derived from the backward position of the bogie-pivot: that the bogie leads better in having the leading wheels more in advance than if the pivot were equidistant from the axles. Not only do the leading wheels turn to the curve with greater facility, but the hind bogie-wheels make less transversal movement towards the outer rail, and, in so much, the guiding of the engine is eased.

The frame consists of two longitudinal frame-plates of iron, 1¼ inches in thickness, 18½ inches deep at the firebox-shell, united transversely by cross-plates. There is no cross motion-plate; the frame-plates are sufficiently stiff without it. The buffer beam is of oak. The side frame-plates of the bogie are of iron, 1 inch thick. The bogie-centre is of Siemens-Martin cast steel.

The wheels and axles are of cast steel throughout. The carrying axles are 5½ inches in diameter at the middle, enlarging to 6½ inches at the journals. The journals are concave in section, the profile being struck with a 30-inch radius, as shown in fig. 893. The concave journals are proved to be of decided advantage as a preventive of undue lateral movement, and obviating grinding friction on the axleboxes. The axles run for several years in good order. The journals of the bogie-axles are 5¼ inches in diameter, by 9 inches long; those of the trailing axle are 5¾ inches by 10 inches. The driving axle is 8¼ inches in diameter, having two cylindrical journals, 8½ inches in diameter, 8 inches long.

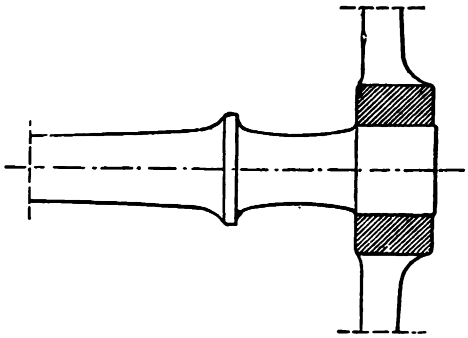


Fig. 893.—Great Northern Railway: Express Locomotive Trailing Axle. Scale 1/16th.

The tyres of the wheels are let on with a fillet, and secured to the wheels with 1-inch screws, let in from the inside of the rim. The tyres are 5⅜ inches wide, 2¾ inches thick, and the tread is sloped at the rate of 1 in 19. The rim of the driving wheels is 2 inches thick, and is carried by 24 spokes, which are pitched at 11½-inch intervals on the rim.

The guide-blocks for the axleboxes are of cast iron, except those for the driving axleboxes, which are of steel, and are wedge-shaped.

The bearing springs deflect at the rate of 5/16 inch per ton of load.

The barrel of the boiler is of ½-inch Yorkshire plates, in three rings lapped telescopically, 4 feet 2 inches, and 4 feet in diameter—widest next the fire-box, 11 feet 5 inches long. The longitudinal seams are double-riveted, and the transverse seams are single-riveted. The tensile strength at the seams is taken as 70 per cent and 56 per cent, respectively, of the normal strength of the plates. The working pressure in the boiler is

140 lbs. per square inch. The factor of safety for the boiler is 4.80. The ends of the shell are stayed with tie-rods pinned to one of the ring-plates—an arrangement which is preferred to through tie-bolts, which are liable to rupture. A mud trap at the bottom of the barrel forms the entrance into the boiler when the tubes are removed. The centre-line of the boiler is 7 feet 3¼ inches above the level of the rails.

The fire-box is of copper plates, of which the tube-plate is ¾ inch thick, the back plate ⅝ inch, and the covering plate ½ inch. The roof is stayed to the shell with ⅞-inch wrought-iron stays placed nearly radial to the curves. The fire-box is constructed with a sloping mid-feather projected from the tube-plate, below the tubes, reaching more than half-way over to the doorway. The combustible gases are deflected towards and mingle with air coming from the doorway under a deflecting plate.

There are 217 brass flue-tubes, pitched at 2⅜ inches, 19/16 inches in diameter outside, No. 11 gauge in thickness at the fire-box, tapered to No. 13 at the smoke-box, 11 feet 9 inches long between plates. The ends of the tubes are fastened by simple drifting, with ferules in the fire-box ends. Mr. Stirling's reasons for the adoption of tubes of so unusually small a diameter were "to bring the columns of heated air more close to the water; and to prevent such large pieces of coal being thrown out of the chimney."

The area of the fire-grate is 17.6 square feet. The heating surface is, in the fire-box, 122 square feet; in the tubes 1043 square feet; together 1165 square feet, or 66 times the grate-area.

The steam-pipe within the boiler is 4¾ inches in diameter, perforated for collecting steam with 400 holes 5/16 inch in diameter, pitched at 9/16 inch, and extending to within 3 feet from each end of the boiler. The pipe is jointed with an unusually long lap, for the sake of stiffness.

The two safety-valves, fig. 894, are 3 inches in diameter, having a flat seat. They are held by a helical spring of ¾-inch round steel.

Fig. 894.—Great Northern Railway: Express Locomotive Safety-valve. Scale 1/4th.

The fire-bars are of cast iron, ⅞ inch thick, with ½-inch air-spaces.

The cylinders are of 1-inch metal, 18 inches in diameter, with a stroke of 28 inches. The steam-ports are 14 inches by 1½ inches, and the exhaust-ports are 14 inches by 3½ inches, having areas respectively 1/12.3 part, and 1/5.3 part of the area of the cylinders. The joint of each valve-chest cover follows the centre-line of the valve-spindle, so that, when the cover is removed, there is ready access to the valve-face of the cylinder. The valve-gear is of the shifting-link type. The expansion-links are 16 inches long between the end-centres. The throw or double-radius of the eccentrics is 6½ inches, and the maximum travel of the valves is 4½ inches. They have 1⅛ inches of lap, and ⅛ inch, fully, of lead; and the maximum cut-off is 90 per cent. In ordinary working the steam is

cut off at 30 per cent of the stroke. The smaller ends of the connecting-rods are fitted with solid gun-metal bushes, with which, without renewal, the engines have run a distance of more than 50,000 miles.

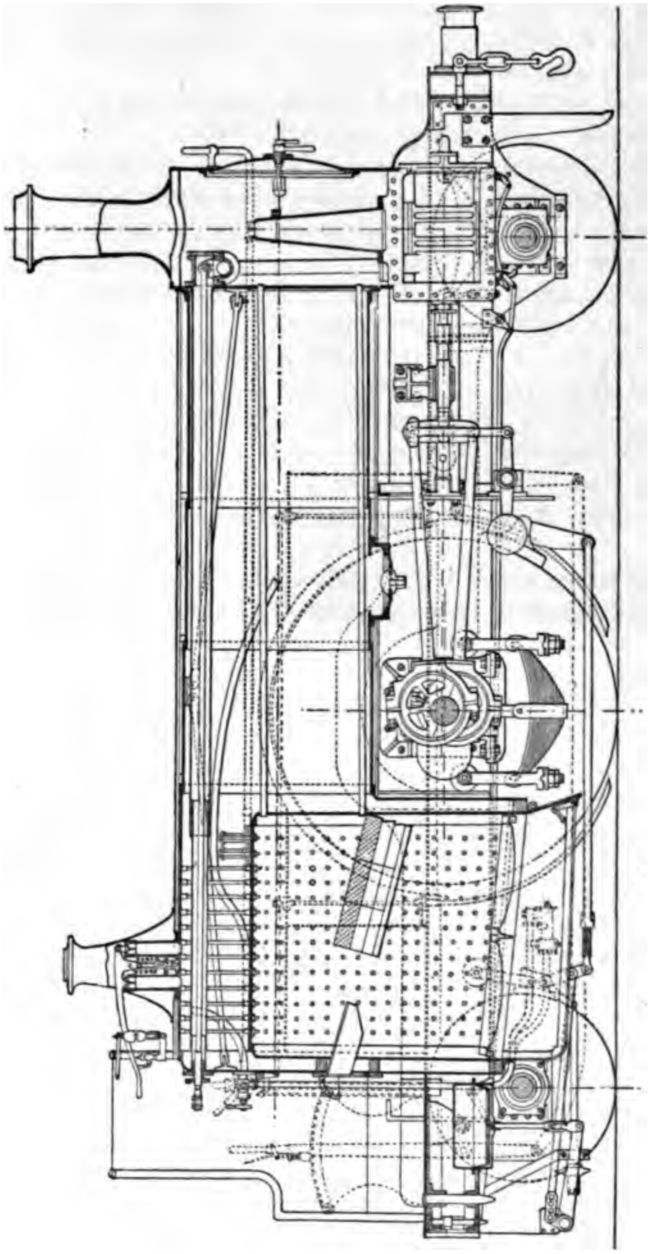


Fig. 895.—Great Northern Railway: Single-wheel Inside-cylinder Express Passenger Locomotive, by Mr. P. Stirling. Longitudinal Section. Scale 1/50th.

The tender for this locomotive is carried on six wheels 4 feet 1½ inches in diameter. It weighs, empty, 19 tons 2 cwts., and has capacity for 3000 gallons or 13.4 tons of water and 5 tons [illegible] ully loaded

tender, a gross weight of 37½ tons. For the locomotive and tender together, the gross maximum weight amounts to 80¾ tons.

Mr. Stirling, on the question of single wheels *versus* coupled wheels, states that he constructed two classes of engines for passenger traffic—one class with four coupled 6½-feet wheels, the other with a single pair of 7-feet driving wheels. The boilers of the two classes were alike; also the cylinders, which were 17 inches in diameter, with a stroke of 24 inches. The working pressure in the boilers was 140 lbs. per square inch. With like trains, the single-wheel engine had the best of it; in fact, it generally beat the coupled engine, in time, from King's Cross to Potter's Bar, a distance of nearly 13 miles, nearly all up-hill, the gradients varying from 1 in 105 for two miles, to 1 in 200. In designing the 8-feet-wheel engine, he determined to employ a large wheel, being satisfied that the larger the wheels the greater the adhesion to the rails; and, as he would not employ inside cylinders, in consequence of the height required to clear the cranks, he placed the cylinders outside, where he could get them between the wheels of the bogie, and in a horizontal centre-line with the driving axle. Engines of this class travel between King's Cross and Leeds or York. The steepest gradients on the route are met with leaving Leeds, ascending 1 in 50, besides the gradient, 1 in 105, leaving King's Cross. The quickest curves have a radius of 15 chains, although the engines pass easily over curves of much shorter radius at York station and elsewhere. Trains of from 16 to 22 carriages are taken with ease from King's Cross station; and on several occasions 28 carriages have been taken, and time has been kept. On one occasion, it is stated, a distance of 15 miles was accomplished in twelve minutes with a train of 16 carriages, making a speed of 75 miles per hour. A train of 33 carriages, full of passengers, has been taken from Doncaster to Scarborough

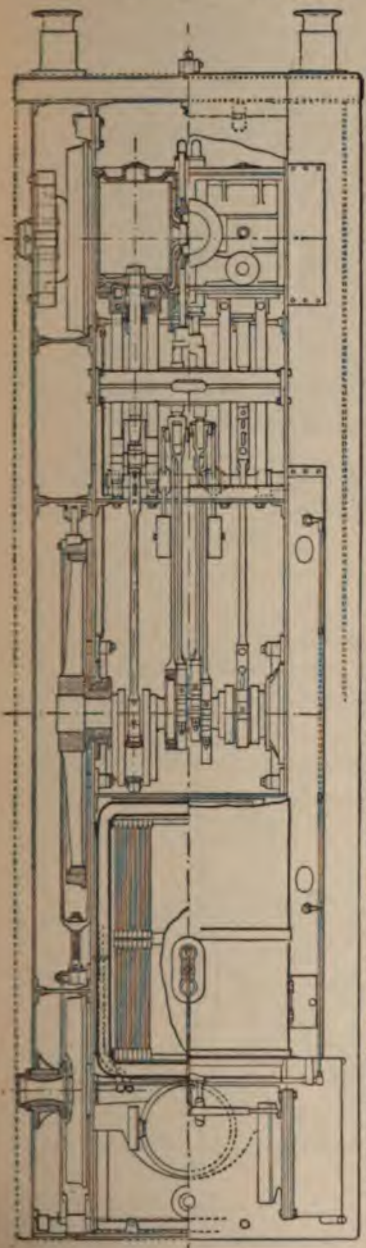


Fig. 896.—Great Northern Railway: Single-wheel Inside-cylinder Express Passenger Locomotive, by Mr. P. Stirling. Sectional Plan. Scale 1/50th.

and back at a speed of 45 miles per hour, with a working steam-pressure of 140 lbs. per square inch. With trains averaging 16 carriages of from

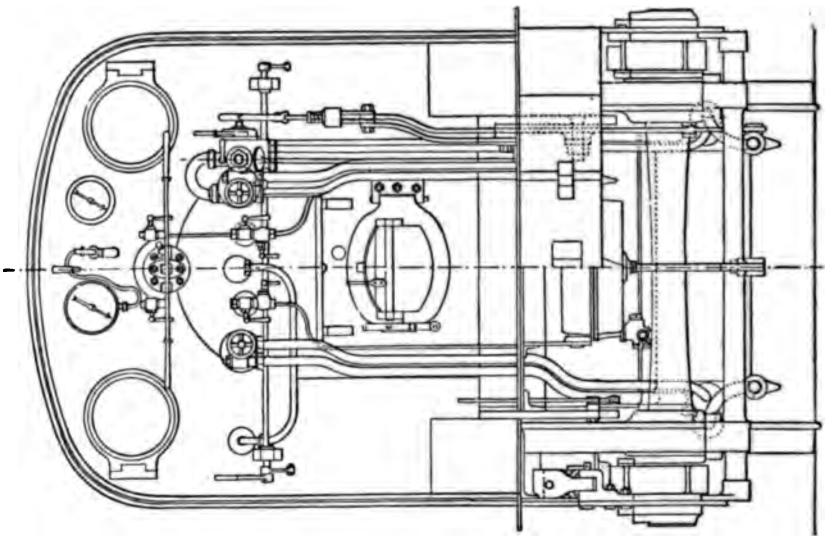


Fig. 898.—Stirling's Inside-cylinder Locomotive: End View at Fire-box. Scale 1/32d.

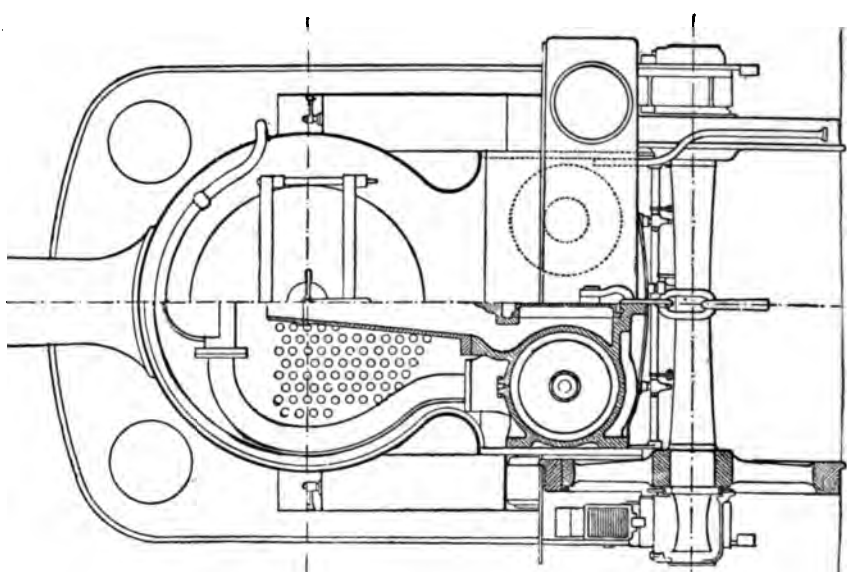


Fig. 897.—Stirling's Inside-cylinder Locomotive: End View and Section of Smoke-box. Scale 1/32d.

10 to 12 tons each, the consumption of coal has been 27 lbs. per mile, including the fuel for getting up steam and for piloting.

The 8-feet-wheel engines are capable of moving a gross weight, cc prising engine, tender, and train, of 356 tons on a level, at a spee'

45 miles per hour. The average results of the regular performance of seven such engines between Doncaster, Peterborough, and London, for the third quarter of 1884, show that a train of 12 six-wheeled carriages, weighing 13 tons each, was taken at a speed of from 50 to 53 miles per hour, for a consumption of 25¼ pounds of coal per mile run, and five pints of oil per 100 miles run.

According to Mr. Stirling's more recent modifications of the outside-cylinder locomotive (1887),[1] the flue-tubes were reduced in number from 217 to 174, and increased in diameter from $1^{9}/_{16}$ inches to 1¾ inches. The feed-water is delivered at the back of the firebox-shell, and conducted inside by a tube to a place about the mid-length of the barrel of the boiler. A pair of Timmis's helical springs, under each driving axlebox, has been substituted for plate springs. The grate-area is 17¾ square feet; the fire-box heating surface is 109 square feet, and the tube surface is 936 square feet, making together 1045 square feet, or 59 times the grate-area.

II. INSIDE-CYLINDER LOCOMOTIVE.

Mr. Stirling lately (1888) designed and constructed a class of express locomotive, figs. 895 to 899, having inside cylinders, 18½ inches in diameter, with a stroke of 26 inches, a single pair of driving wheels, 7 feet 7½ inches in diameter, a single pair of leading wheels, 4 feet 1½ inches in diameter, and a pair of hind wheels of the same size. The wheel-base is 19 feet 1 inch in length The boiler is of the same size as in the 8-feet-wheel engine, having 186 flue-tubes 1¾ inches in diameter, ⅝ inch apart, 1109.7 square feet of heating surface, and 18.4 square feet of grate. The reason for constructing this new class was that they are less costly to construct and maintain than the 8-feet-wheel engines, although in no other respect superior. The consumption of fuel is at the

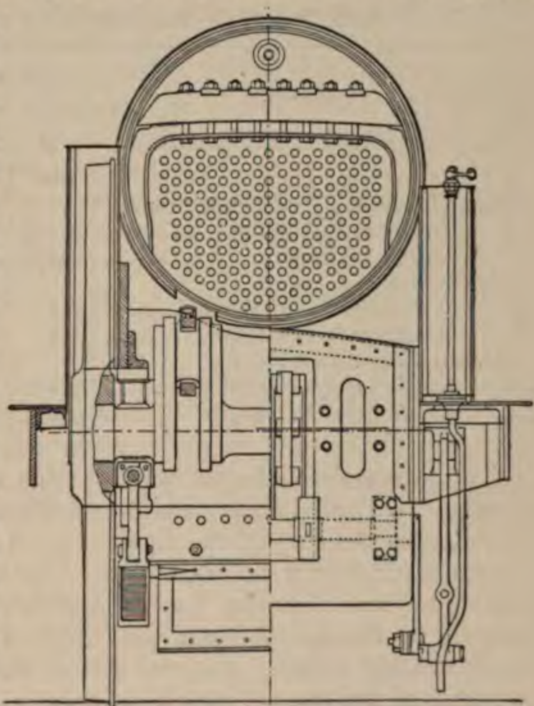


Fig. 899.—Stirling's Inside-cylinder Locomotive: Transverse Section. Scale 1/32d.

rate for asses, on the same duty. By dispensing with the

Eng 1887, for illustrations and description of Mr. Stirling's locomotive

bogie in the new class, the weight of material in that respect is reduced by a few tons; and it is argued, in consequence, that economy of fuel is not realized simply by the employment of the bogie in place of a single pair of wheels. The engine weighs in working order 44 tons; the tender, with 2900 gallons of water and 5 tons of coal, 30 tons. The consumption of fuel, during the race to Edinburgh in the summer of 1888, with a train load of 120 tons, was at the rate of 22.6 lbs. per mile, including fuel for raising steam.

Chapter LXV.—THE RAILWAY RACE TO SCOTLAND.

In the summer of 1888, the three great metropolitan railway companies that start from Euston Square, St. Pancras, and King's Cross, with one consent determined to beat their own record, culminating in the "Race to Edinburgh." The average speeds, reckoned inclusive of stoppages, and the average actual running speeds, are given in the following table, No. 181. The maximum running speeds attained between stopping stations are added:—

Table No. 181.—Railway Race to Scotland, 1888.

Railway.	Length of Journey.	Duration of Journey.	Average Speeds, inclusive of Stoppages.	Average Actual Running Speeds.	Maximum Speed between Stations.
	miles.	h. m.	miles per hour.	miles per hour.	miles per hour.
L. and N.W.R., West Coast Route:					
Euston to Edinburgh	400¼	8 0	50	53½	54
Euston to Glasgow	401½	8 57	45	49	52.66
Midland Ry.:					
St. Pancras to Edinburgh	413	9 44	42.4	46¼	51.33
St. Pancras to Glasgow	423	9 22	45	49	51.8
G.N.R., East Coast Route:					
King's Cross to Edinburgh	392½	7 45	50.66	54	56¼
King's Cross to Glasgow	439¾	9 45	45	49¼	53¼

The locomotives selected for the racing competition deserve a special mention. On the London and North-Western Railway, an engine, the Waverley, of the class of the Lady of the Lake, having outside cylinders, was employed to run the train (four 8-wheel carriages, weighing with passengers 80 tons) between Euston station and Crewe. This class was designed by Mr. Ramsbottom, and exhibited in 1862. It has 1098 square feet of heating surface, 15 square feet of fire-grate, 17-inch cylinders with 24 inches of stroke; and weighs 27 tons in working order. From Crewe to Carlisle, the train was taken by one of the Precedent class, four-coupled-wheel engines, designed by Mr. Webb. From Carlisle to Edinburgh and Glasgow, on the Caledonian Railway, the train was taken by one of Mr. Drummond's express engines, having a single pair of 7-feet driving wheels, with a leading bogie, 18-inch cylinders with a stroke of 26 inches;

1085 square feet of heating surface, 17.4 square feet of fire-grate; weight, 42 tons.

From St. Pancras, the single-driving-wheel express engines of the Midland Company, already described, page 503, were employed.

On the Great Northern Railway, the inside-cylinder engine, with 7½-feet driving wheels, of 1888, already noticed, page 565, was employed in the race. On the North Eastern and North British systems the trains were drawn by one of Mr. Worsdell's compound express locomotives, to be described in a following section on compound locomotives.

CHAPTER LXVI.—FOUR-COUPLED EXPRESS PASSENGER LOCOMOTIVE.

DESIGNED AND CONSTRUCTED BY MESSRS. SHARP, STEWART, & CO., FOR THE PARIS EXHIBITION, 1878.

(Cylinders 18 inches in diameter; stroke 25 inches; wheels 6½ feet; gauge of way 4 feet 8½ inches.)

The six-wheel locomotive, figs. 900 and 901, constructed for the Paris Exhibition, 1878, and afterwards purchased by the Paris-Orleans Railway Company, is an excellent example of the prevailing style of four-coupled express passenger locomotive, with a pair of leading wheels, with bearings in fixed axle-guards. Several engines of the same type were previously constructed for the South-Eastern Railway.

The cylinders are inside, the trailing wheels are coupled to the driving wheels, and these with the leading wheels are all placed well forward, in relation to the boiler, the leading axle being close to the cylinders, the trailing axle close to the firebox-shell, and the driving axle 25½ inches in advance of the firebox-shell; resulting in a wheel-base of 16 feet 3 inches, of which 8 feet 8 inches is placed between the coupled axles, and 7 feet 7 inches between the leading and driving axles. The cylinders are inclined upwards towards the front, at an angle of 1 in 10, in order to clear the leading axle. The effect of this disposition is that the greater proportion of load is placed on each of the coupled axles, available for adhesion, and less than one-third of the total is placed on the leading axle, as shown by the following distribution:—

	Tons.	Cwts.	Qrs.
Engine full:—Leading wheels	10	10	2
Driving do.	12	14	2
Trailing do.	12	4	0
Total	35	9	0
Engine empty	32	2	2

From this distribution of weight, it appears that the driving axle is in advance of the centre of gravity by 8¾ inches. The method of calculating the position of the centre of gravity has already been exemplified, page 505.

The framing is of iron, constructed for inside bearings, and consists of

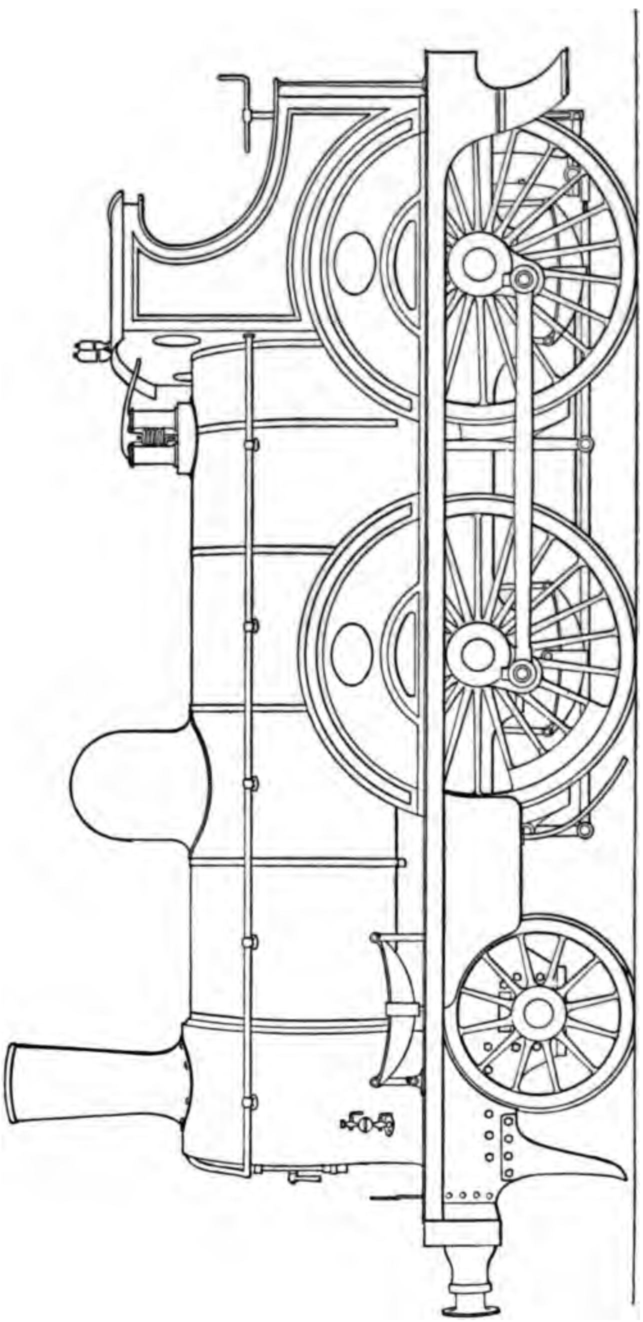
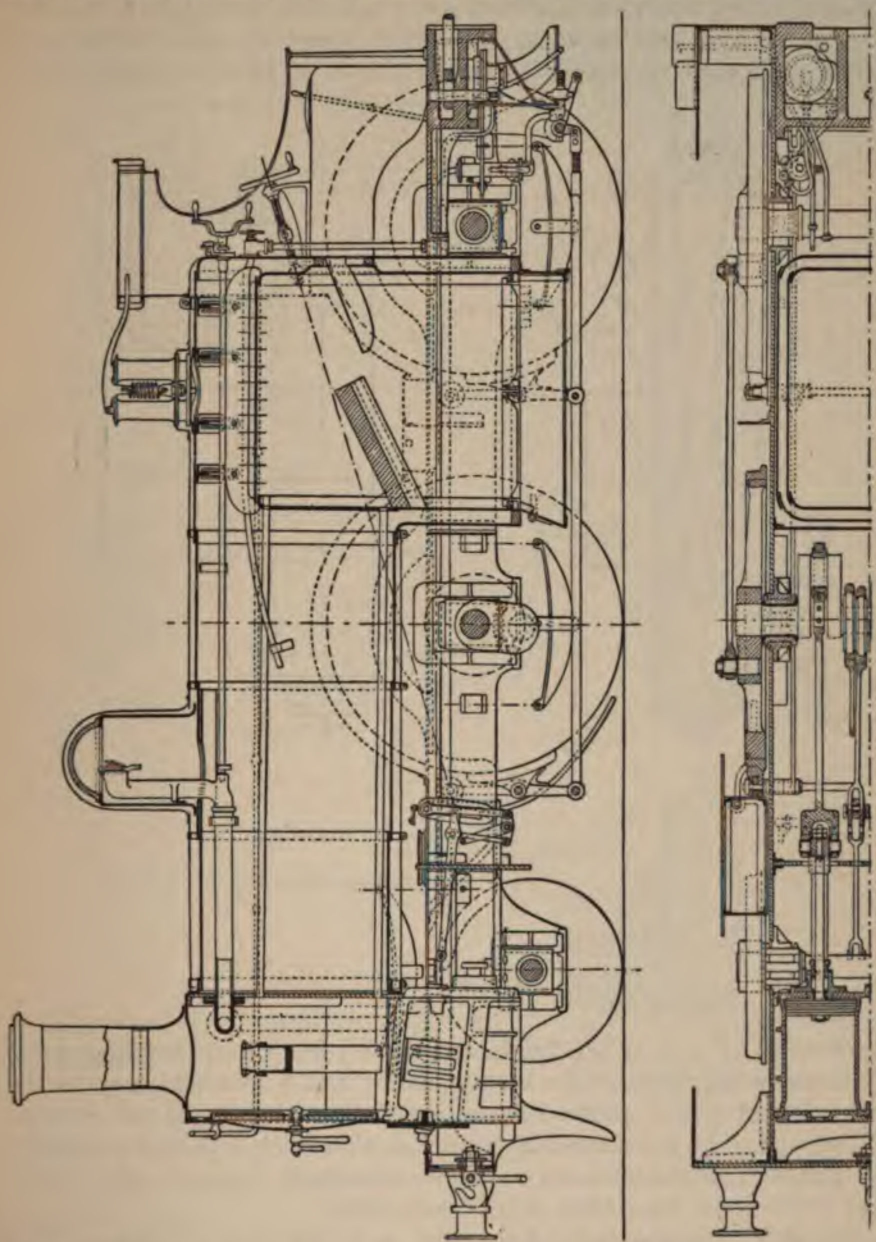


Fig. 900—Express Passenger Locomotive, designed and constructed by Sharp, Stewart, & Co.

two straight longitudinal ·plates 1 inch thick. p in the body,

4 feet 1½ inches apart; connected by the buffer-plate 1¼ inches thick, 18 inches deep; and by the cylinders, the motion-plate, the back-stay plate

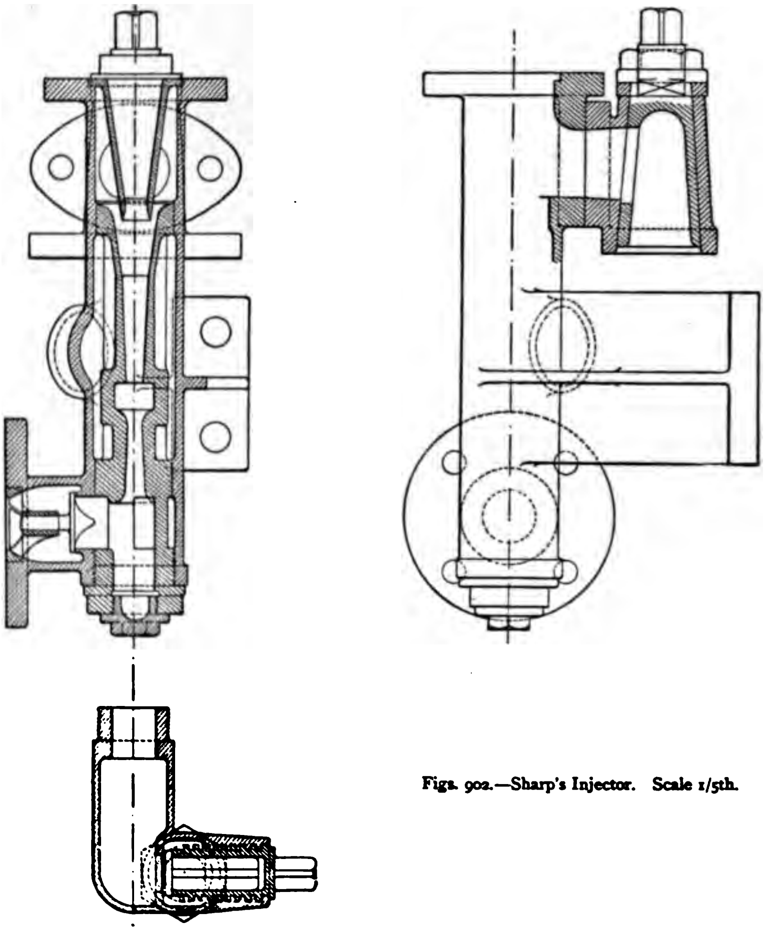


Figs. 901.—Sharp's Express Locomotive: Sectional Elevation and Plan. Scale 1/50th.

in front of the fire-box, and a cast-iron platform behind the boiler. The side-plates are 24 feet 9 inches long.

The boiler is of best Yorkshire iron. The barrel is in three rings of plates, telescopically lapped, reducing in diameter towards the smoke-box,

having the mean diameter 4 feet 2 inches inside, of ½-inch plates; and 10 feet 3 inches long. But the smoke-box tube-plate is ⅞ inch thick. The firebox-shell is 5 feet 10 inches long, 4 feet ½ inch wide outside, of 9/16-inch plates at the front and the back, with a ½-inch covering-plate. The upper part is flush with the barrel. The fire-box is of ½-inch copper plates,



Figs. 902.—Sharp's Injector. Scale 1/5th.

thickened to ⅞ inch at the flue-tubes. It is 5 feet 1⅞ inches long, 3 feet 5¼ inches wide, inside, at the bottom, and 5 feet 5 inches high above the grate. It has 3-inch water-spaces at the front and back, at the bottom; 2½-inch spaces at the sides. It is fitted with a brick arch and a deflector door-plate. The steam-dome, 24 inches in outside diameter, of 9/16-inch plate, is placed on the middle ring of the barrel.

The rivets are 13/16 inch in diameter, and pitched at 1⅞ inches. The vertical seams of the boiler are single-riveted, with 2¼ inches of lap. The vertical seams next the fire-box are double-riveted, with 3½ inches of lap. The longitudinal seams are double-riveted, with butt-seams, and 7⅜-inch welts inside and outside.

A pair of 3½-inch safety-valves, held by one helical spring between the valves, on Ramsbottom's system, is fixed on the top of the firebox-shell. One No. 9 mm. injector is fixed at the left-hand side, under the foot-plate, and one No. 7 mm. injector at the right-hand side. The working pressure is 140 lbs. per square inch. The smoke-box is 2 feet 8 inches long, and the chimney is 16 inches in diameter.

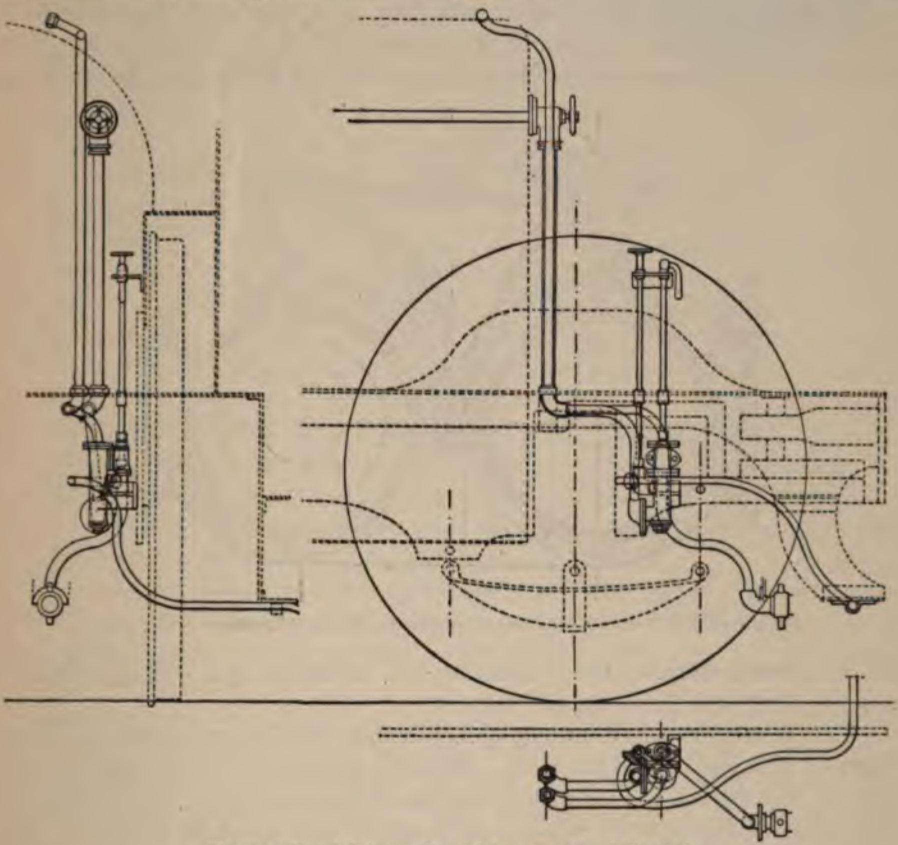


Fig. 903.—Sharp's Injector: General Arrangement. Scale 1/32d.

There are 219 brass tubes 1⅞ inches in diameter outside, pitched at 2½ inches; 10 feet 6½ inches long between plates.

The area of fire-grate is 17¾ square feet. The heating surface of the fire-box is 105 square feet; that of the flue-tubes is 1134 square feet; together, 1239 square feet, or 70 times the grate-area.

The most recent form of Sharp's injector is shown in figs. 902, and the general arrangement of piping is shown in fig. 903.

The cylinders are 18 inches in diameter, with a stroke of 25 inches, 1 inch thick, bolted together and to the side frame-plates. To make room for the valves, the valve-faces are inclined upwards and outwards, as show in the cross section, fig. 904. The steam-ports are 14 inches by 1½ inche having an area 1/12th of that of the cylinders; the exha i

$3\frac{1}{4}$ inches long, having $^1/_{5.6}$ part of the cylinder-area. A single pair of guide-bars is provided for each cylinder, $4\frac{1}{2}$ inches wide, 10 inches apart, fixed with two bolts and nuts to the cylinder-cover, and with one bolt and nut to the motion-plate, 1 inch thick, through which they project or overhang for a length of 10 inches. By this disposition, in which the motion-plate is placed further from the driving axle than usual, additional room is provided for the Allan valve-gear, the reversing shaft and levers of which are placed in advance of the expansion-links. There is also the advantage of a more nearly direct support of the guide-bars for resisting

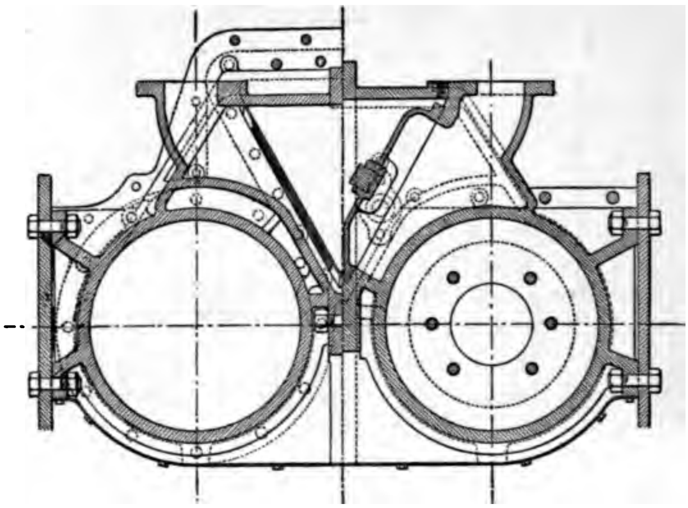


Fig. 904.—Sharp, Stewart, & Co.'s Express Locomotive: Section of Cylinders. Scale 1/16th.

the maximum stress of the connecting-rod, at half stroke. The guide-bars are provided with liners for adjustment.

The piston is of cast iron, $3\frac{3}{4}$ inches thick, having two plain packing-rings of gun metal, $\frac{7}{8}$ inch wide. It is $\frac{3}{8}$ inch clear of the cover at each end of the stroke. The piston-rod is of Bessemer steel, $2\frac{3}{4}$ inches in diameter, let through the piston and fastened with a nut on the end. The other end of the rod is let into and through the crosshead with a slight taper, and fastened with double-nuts on the end. The crosshead is of wrought iron, case-hardened, in one piece with two overhanging $2\frac{3}{4}$-inch gudgeons for the connecting-rod. The slides are of cast iron, 14 inches long, one above and one below the crosshead.

The connecting-rod is 6 feet long, or $5\frac{3}{4}$ times the length of the crank. It is forked at the smaller end with two bearings to take the gudgeons of the crosshead. The straps at both ends of the rod are each fastened with two bolts and nuts, and have separate cotters.

The axles are of Bessemer steel. The driving axle is 7 inches in diameter at the middle, and the trailing coupled axle $6\frac{3}{4}$ inches. The journals are $7\frac{1}{4}$ inches in diameter, 9 inches long; and the wheel-seats are $8\frac{1}{2}$ inches in diameter. The inside crank-pins are $7\frac{3}{4}$ inches in

diameter, 4 inches long; the webs of the cranks are 4⅛ inches thick by 14 inches. The leading axle is 6 inches in diameter, with 6¼-inch journals 10 inches long, and 7½-inch wheel-seats.

The valve-gear is, as before stated, on Allan's system, in which the expansion-link and the valve-rod link, or radius-link, are linked to the ends of short levers on a transverse reversing shaft, as already fully explained, page 24. The expansion-link is 2¼ inches thick, 16 inches long between the end centres, allowing 9¾ inches range of the block in the slot. The eccentrics are 15½ inches in diameter, with 6 inches of throw; the eccentric-rods are 4 feet 1 inch long; and the radius-rod is 3 feet 4¾ inches long. The lap of the valve is 1 inch, the lead is 5/32 inch, and the travel in full gear forward is 4 1/32 inches, cutting off at 71 per cent of the stroke. The valve-spindles are 1⅝ inches in diameter, and are guided through stuffing-boxes at both ends.

The driving wheels are 6½ feet in diameter; and 6 feet 1 inch over the rim, which is 1¾ inches thick. They have each 22 spokes. The tyres are of crucible cast steel, 2½ inches thick, 5¼ inches wide, lapped on to the rim with a fillet, and fastened by screws through the rim. The outer crank-pins are let into bosses on the coupled wheels, at a radius of 12½ inches, diametrically opposed to the near inside cranks, which are counterweighted in addition by masses of metal forged solid to the rims. The nave has a bearing 7 inches long on the axle. The balance-weights are calculated and applied according to the rules laid down by Mr. D. K. Clark in *Railway Machinery*, pages 165, &c. They are forged solid in the wheels between the spokes.

The leading wheels are 4 feet in diameter over the tyres; 3 feet 7 inches over the rims, which are 1 9/16 inches thick; the tyres being the same as the others. There are 12 spokes in the wheel. The nave has a bearing 6½ inches long on the axle.

The axleboxes of the coupled axles are of wrought iron, case-hardened. The leading axleboxes are of cast iron, with gun-metal steps. They have sliding caps, to admit of 1-inch side play of the axleboxes, to ease the passage of the engine on curves. They slide on a double incline, in order that they may automatically come into alignment on entering the straight line. The guides for the driving and trailing axle-boxes are of crucible cast steel, of horse-shoe form, having two sides and a top for the sake of strength.

The bearing springs are of one size, having 13 plates, 4½ inches wide, ½ inch thick, with a 3½-feet span.

A steam break, on Webb's system, is supplied. It has a 9-inch steam cylinder, and acts on the front of each coupled wheel.

It is stated that this engine is capable of drawing a train weighing 183 tons gross up an incline of 1 in 100, at a speed of 30 miles per hour, in addition to the weight of the engine and tender, with 98 lbs. effective mean pressure per square inch in the cylinders, taking the total resistances at 42.4 lbs. per ton. Or, it can take the same train on a level at a speed

of 50 miles per hour, with 62 lbs. per square inch effective mean pressure in the cylinders, and taking the total resistance at 26.6 lbs. per ton.[1]

The tender is on three axles, and weighs, empty, 11 tons 18 cwts. It has capacity for 2500 gallons of water, and 3½ tons of coal.

CHAPTER LXVII.—FOUR-COUPLED-WHEEL EXPRESS PASSENGER LOCOMOTIVE.

DESIGNED BY MR. WILLIAM STROUDLEY, FOR THE LONDON, BRIGHTON, AND SOUTH COAST RAILWAY.[2]

(Cylinders (inside), diameter 18¼ inches, stroke 26 inches; driving wheels 6½ feet; gauge of way 4 feet 8½ inches.)

This engine, shown in outline, fig. B, page 488, and in fig. 905 annexed, as an express passenger-train engine, is distinguished by the coupling of the leading wheels to the driving wheels; and by several new details. It had become necessary to provide a passenger engine of somewhat greater power than the ordinary engines having 17-inch cylinders, with a 24-inch stroke. In 1876, Mr. Stroudley constructed six engines with 17¼-inch cylinders, 26-inch stroke, and 6½-feet wheels coupled in front; weighing each, in working order, 36 tons. The cylinders were placed 26 inches apart between centre-lines; and the slide-valves were placed between them, the exhaust being divided, so that the steam from the lower half of the port was passed under and round the cylinder, and met the steam escaping from the upper half at the base of the blast-pipe. On this system, cylinders up to 17¼ inches in diameter could be placed between the frame-plates, at the same time that the driving axle could be made with a stronger inside crank. Engines of still greater power being required, Mr. Stroudley entirely rearranged the cylinders, casting the two cylinders in one piece, as in fig. 906, removing the valves to a position underneath the cylinders, placing the cylinders nearer together, at a central distance apart of 25 inches, making room for 18¼-inch cylinders, with crank-checks and axle-journals of liberal dimensions. The valves are placed in an inverted position, the steam-ports leading from the bottom of each cylinder. The curvature of the ports is easy, and the exhaust is discharged almost directly up to the chimney. Water is freely drained from the cylinders, and waste-cocks are not required. The oil from the cylinders passing through the ports lubricates the valve-faces in such a manner as to reduce the wear of the slides nearly to nothing. The first engines fitted with these cylinders were built by Mr. Stroudley in 1870.

To supply steam for these cylinders, the barrel of the boiler was

[1] The subject of the resistance of engines, tenders, and trains we investigated by the author in *Railway Machinery* (1855), page 291, &c.

[2] This notice is based upon Mr. Stroudley's paper on " Engines," in the *Minutes of Proceedings of the Institution* o 1885.

increased to 4½ feet in diameter outside, and the fire-box was increased in length to 6 feet.

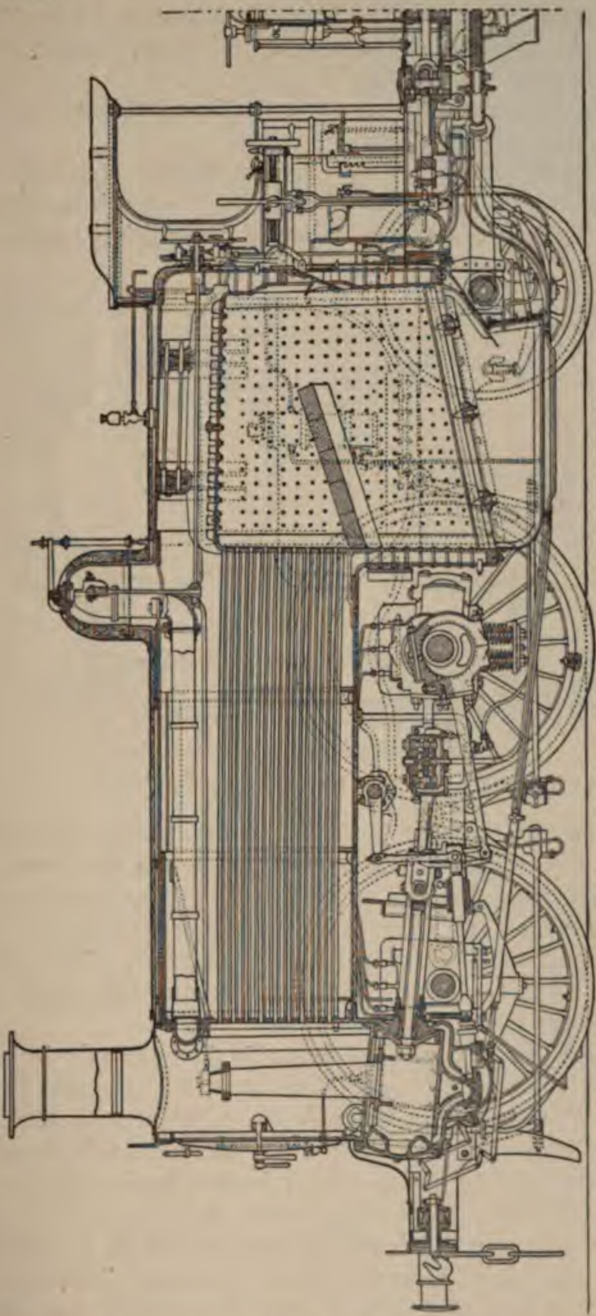


Fig. 905.—London, Brighton, and South Coast Railway Standard Express Passenger Locomotive, by Mr. Wm. Stroudley. Scale 1/50th.

Referring to the illustration, fig. 905, of the "Gladstone" locomotive, two coupled axles are 7 feet 7 inches apart between centre-lines; the

trailing axle, placed under the end of the fire-box, is 8 feet from the driving axle, making a total wheel-base of 15 feet 7 inches. The cylinders are inclined upwards towards the front at an angle of 1 in 11½, to clear the leading axle; and the valves and spindles are, for the same reason, inclined downwards at the angle 1 in 15.

The boiler and machinery are so proportioned that the working stress is limited to 3 tons per square inch of section.

The side frame-plates are of Siemens-Martin steel, of from 28 to 30 tons tensile strength per square inch. They are 1 inch thick, 19 inches deep at the part between the cylinders and the driving axle. They are

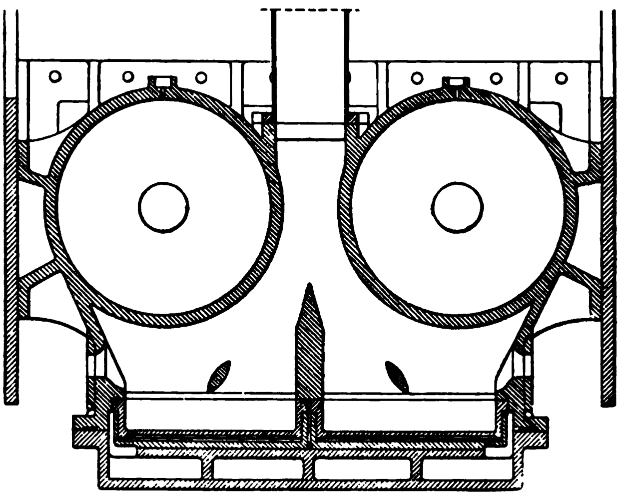


Fig. 906.—Stroudley's Locomotive Engine: Section of Cylinders. Scale 1/16th.

stayed together by the front buffer-beam, of 1½-inch steel, stiffened for the draw-bar; also by the cylinder castings, by the steel motion-plate, by a flanged iron plate in front of the fire-box, and by a portion of the foot-plate which is riveted to angle-irons extending from the fire-box to the back buffer-beam, which is of 1¼-inch steel plate. The length of the frame-plates is 25 feet 9 inches. The total length of the engine and tender is 51 feet 10 inches over the buffers.

The cylinders, fig. 906, are 18¼ inches in diameter, of 1-inch metal, with a stroke of 26 inches, cast in one piece, at 25 inches apart between their centre-lines. The weight of the pair of cylinders with the valve-chests and studs, not including the valves, covers, or pistons, is about 26½ cwts. The steam-ports are 1⅜ inches by 15 inches, having an area $^1/_{12.7}$ part of that of the cylinder. The exhaust-port has $^1/_{8.7}$ part of the cylinder area. Mr. Stroudley proportioned the steam-ports at the rate of 1 square inch for every 250 cubic inches of cylinder capacity. The lap of the valve is ⅞ inch, with a lead of $^1/_{16}$ inch. For slow-pulling engines up to ¼ inch is applied; for fast-running engines, ther or clearance up to ⅛ inch. Steam is supplied to th

ends. The blast-orifice is $4\frac{9}{16}$ inches in diameter, and is 14 inches below the crown of the smoke-box.

The pistons are cast of gun-metal, of a conical form, combining strength with simplicity, and to permit the contraction in cooling when cast, without severe initial stress. The coniform piston admits of a coniform cover, into which the stuffing-box is recessed; so gaining a few inches of extra length for the connecting-rod. Wakefield's packing-rings are used. These rings are of cast iron, $\frac{3}{4}$ inch wide, $\frac{7}{16}$ inch thick, turned to $\frac{1}{4}$ inch larger diameter than the cylinder; and then having a section $\frac{3}{4}$ inch wide slotted out, the ring being sprung into its place. Steam is admitted through small holes in the piston inside the rings.

The piston-rod and the valve-spindles are packed with Jerome packing, fig. 907, consisting of rings made of tin, which are held in a conical receptacle round the rod, and are kept tight as they wear by means of a helical spring in the inner part of the stuffing-box.

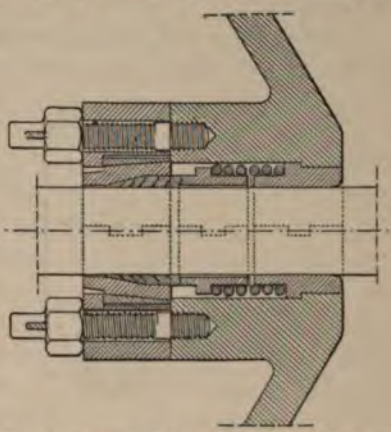


Fig. 907.—Stroudley's Locomotive: Jerome Packing for Piston-rods. Scale 1/6th.

The piston-rod is of steel, of an ultimate strength of 33 tons per square inch, $2\frac{3}{4}$ inches in diameter; fastened to the piston with a steep conical bearing, and a gun-metal or manganese-bronze nut. The crosshead is one piece with the piston-rod. The gudgeon is of best Yorkshire iron, forged from old tyres, case-hardened, forced into the crosshead by hydraulic pressure. The cast-iron slide-blocks are 11 inches long, 3 inches wide; they are forced by hydraulic power on the ends of the gudgeon. The guide-bars are of a trough section, being cast with a vertical web at each outer side, which forms a shield outside the slide-blocks, and confers a great degree of stiffness. The motion-plate is of tough steel, and besides holding the guide-bars it makes an efficient stay for the side frame-plates, to which it is riveted by double-flanges. The guide-bars are supported by the motion-plate at about the middle of their length, where the greatest angular stress of the connecting-rod—at half-stroke—is to be resisted. At the lower part of the motion-plate two tubular guides for the valve-spindles are cast in one piece with it, bushed with gun-metal.

The connecting-rod is of tough iron, forged from old Yorkshire tyres, $6\frac{1}{2}$ feet long, or six times the length of the crank. This is a standard length for the connecting-rods of all the classes of engines on the line. The rod is $2\frac{15}{16}$ inches in diameter at the crosshead end, $3\frac{1}{2}$ inches at the crank end, uniformly tapered; having a minimum sectional area of $\frac{1}{4}$ square inches at the cotters and other parts. The bolts fixing the to the larger end are $2\frac{1}{8}$ inches in diameter; and are reduced to a m area of section by drilling out the centre of the plain part, up

to the beginning of the screw-thread. They have only one nut, of seven threads per inch.

For axle-bearings on the Brighton Railway, 8 inches is the standard length of journal for engines and tenders, and also for carriage and wagon stock. The crank-axle is of steel, 7¾ inches in diameter at the middle, 8¼ inches at the crank-pin and in the wheels; and it is 8 inches at the journals. The placing of the cylinders 25 inches apart between their centre-lines, makes room for crank-webs 5 inches in thickness; they are 11 inches wide. Each web is fortified by a "hoop" or strap shrunk over it, 3½ inches by 2½ inches in section.

The leading coupled-axle is of iron, 7 inches in diameter; 8 inches at the journal, 8¼ inches in the wheels. The trailing axle is of iron, 6½ inches in diameter in the middle, 7 inches at the journal; 7½ inches in the wheels.

The driving and leading wheels are 6½ feet in diameter over the tyres, 6 feet at the rims; they have 22 spokes, landed on the rim at 9½-inch intervals. The rim is 2 inches thick, 4½ inches wide. These proportions are unusually strong. Mr. Stroudley had observed that tyres on rims of usual thickness break, in nearly all cases, near a defective point in the rim of the wheel; a tyre, if allowed to wear down below 1½ inches in thickness, is almost certain to break, in consequence of deflection between the spokes. With the 2-inch rims it is found that tires may be run down until they become slack by elongation. The tyres, fig. 908, are of cast steel, of 48 tons tensile strength per square inch; 3 inches thick, 5¼ inches wide; cylindrical at the tread for the driving wheels, inclined conically at the rate of 1 in 24 for the leading wheels. They are notched on to the rims at the inside, and fixed by 1-inch screws let in from the inside of the rim in every alternate interspace. The wheels are bored to such a diameter as to require an end pressure of 12 tons for every inch of diameter of the axle, to force it on the axle. Thus forced on, the wheel is retained in position without keys or collars—solely by the elastic nipping action of the metal. Next, the crank-pin holes are bored. The crank-pins are cylindrical, 4½ inches in diameter in the wheels, 4 inches at the journals, which are 4¼ inches long. They are case-hardened, ground up true, and forced into the wheels, with the same proportions of end pressure as are adopted for the axles. The rims of the wheels are turned, and the tyres shrunk on by being slightly heated and cooled, the shr' ' foot of diameter being—

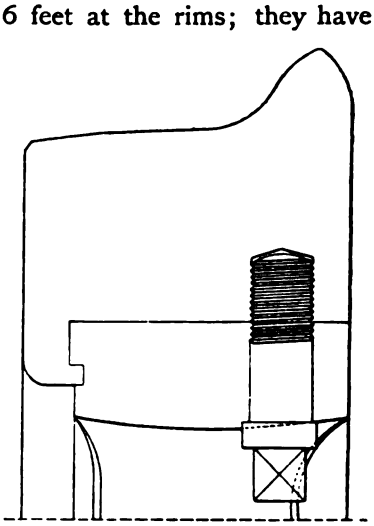


Fig. 908.—Stroudley's Locomotive: Section of Leading Tyres. Scale 1/3d.

For 4 feet internal diameter	............No. 19	Birmingham	wire-gauge.
„ 5 „ „	............No. 18	„	„
„ 6 „ „	............No. 17	„	„

The naves of the wheels are constructed with the central ends of the spokes reduced or tapered to a point in the direction of the centre-line of the nave. A washer of corresponding shape—thickest at the centre—is applied and welded to the spokes at each side. The driving tyre-flanges are only ⅝ inch thick. By such reduction the cross strains on the axle by blows of the rails are obviated, and the number of breakages of crank-axles reduced.

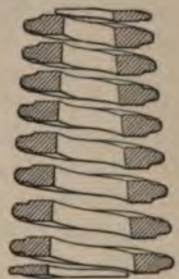


Fig. 909.—Stroudley's Locomotive: Bearing Spring. Scale 1/8th.

The trailing wheel is 4½ feet in diameter; it has tyres 3 inches thick.

The side bearing springs are placed below the axle-boxes. The leading and trailing springs are of steel plates, 5 inches wide, 3½ feet in span, deflecting 5/16 inch per ton of load. The leading springs have 18 plates, of which 16 are ⅜ inch thick and 2 are ½ inch thick. The trailing springs have 16 plates—14 of ⅜-inch plate, 2 of ½-inch plate. The driving springs, fig. 909, are spiral, on the Timmis system, a pair to each axlebox. They are 7 1/16 inches in diameter at the base, 5⅜ inches at the top, 11⅜ inches high, unloaded; and they deflect at the rate of 11/16 inch per ton of load.

The eccentrics are of cast iron, 16 inches in diameter, half of each pair being cast in one piece: fastened together by four screw-bolts recessed on the face of the eccentric—the opening being filled up with white metal to prevent the screw slacking back. The throw is 5½ inches. The eccentrics are checked upon the neighbouring crank-arm, by which they are driven. The eccentric-straps are of cast iron, bolted together with two long 1¼-inch bolts and one deep nut to each, secured by a cotter. The straps are projected outwards at their junctions as cantilevers, to give greater width of bearing on each other, and greater stiffness. These straps show very little wear after ten years' use; and no liners for letting together are provided. The eccentric-rods are 4 feet 7 inches long. The expansion-link is 17 inches long between the end centres, 3 inches thick, curved to a 4-feet-7-inch radius. It is suspended at the centre of its length, the point of suspension being at half the versed sine or camber of the link. By this disposition equal distribution of the steam is effected, cutting off at from 78 per cent to 12 per cent.[1] The spindles are, for convenience, 2⅜ inches off the centre-lines of the valves. The travel of the valve in full-gear is 3¾ inches, with a lead of 1/16 inch. In mid-gear the travel is 2¼ inches. The reversing-gear is a triple-thread screw of 1½ inches pitch, having a long

[1] Sir Daniel Gooch recognized the advantage of an adjustment of the point of suspension of the expansion-link, for effecting equal distribution in the Great Britain class of locomotives on the Great-Western Railway. See *Railway Machinery*, page 44, &c., for a full investigation of this question.

nut. The screw is cut on the end of the reversing-rod. The valve-spindle is 2 inches in diameter; the extension is 3½ inches in diameter for guiding surface.

The outside crank-pins in the driving and leading wheels are placed at a radius of 9 inches or 10 inches, which is much less than that of the inside crank—13 inches; "and when the stress of the steam is applied to the inner crank-pin, the outer crank-pin takes its share of the reaction, leaving but little for the axle-boxes to carry except the first thrust when on the centre. The axle-boxes and brasses of these engines run for many years without being adjusted, and a broken inside or outside rod is unknown." The adoption of this practice of outside cranks of considerably less radius than the radius of the inside cranks, is partially explained by the practice of Mr. Stroudley in placing the outside crank-pins on a radius-line coincident with that of the inside crank, instead of being placed diametrically opposite as is elsewhere practised:—"When the thrust of the connecting-rod," he said in reference to the usual practice, "is driving the crank-shaft in a backward direction the axle is forced to the back side of the axle-box, and the axle-box to the back face of the horn-block; but, before assistance can be obtained from the outside rod on that side of the engine in propelling the train, the latter must be put in tension; and before this can take place the whole of the distance which the crank-shaft is moved backwards, and the whole of the play of the side-rod, brasses, &c., must be taken up by the slipping of the wheels. This causes great wear and tear of the crank-pins, and heavy strain on the connecting-rods, which do their work by a series of blows instead of taking it up smoothly, as when the cranks are placed both on the same side of the axle, which has been the author's (Mr. Stroudley's) practice since 1866." To adjust the counterweights applied in the wheels, they are calculated for each cylinder separately, to balance all the revolving masses in full. Two-thirds of the connecting-rod measured from the crank end are taken as revolving weight. Of the simply reciprocating parts—the other third of the connecting-rod, the piston and rod, side-blocks and pump-ram—two thirds are reckoned for balancing. A mass equivalent to the total of these portions is divided between the two wheels on the same axle, in the inverse ratio of their distances from the centre-line of the cylinder. Thus, for each wheel a larger and a smaller mass is calculated, and the centre of gravity of the two masses is the centre of gravity of the combined or resultant mass.[1]

The outside coupling-rods are constructed with solid ends, bushed with gun-metal. Some of the bushes have lasted upwards of fourteen years without renewal.

The shell of the boiler is of Yorkshire iron, except the smoke-box tube-plate, which is of Siemens-Martin steel, being less liable to corrosion and more easily flanged than iron.

[1] See a very full investigation of the coun[illegible] *Railway Machinery*, 1855, page 172, &c.

The barrel is 10 feet 2½ inches long, 4½ feet in diameter outside, of ½-inch plates, in three rings, telescopically lapped, being reduced in diameter towards the smoke-box. The circular seams have 2½ inches of lap, with ¾-inch rivets at 2 inches of pitch. The longitudinal seams are butt-jointed with double covering straps, 9¼ inches by 5/16 inch thick, double-riveted, with ⅞-inch rivets at 3¾ inches of pitch. The strength of this joint, as stated, is 76 per cent of that of the whole. The firebox-shell is 6 feet 8¼ inches long outside, 4 feet 1 inch wide at the bottom, which is sloped 15 inches downwards towards the front. The front and back plates are ⅝ inch thick, the covering-plate ½ inch. The seams under water are plastered with red-lead and plated with copper, in order to prevent rusting. The fire-box is of copper plates ⅝ inch thick, made up to 1 inch at the flue-tubes. It is 5 feet 10 inches high at the front, 4 feet 6¾ inches at the back. It is riveted with iron rivets. The walls are stayed to the shell with ⅞-inch copper stays at 3¾ inches pitch. The roof is supported by eight wrought-iron girder-stays, having solid bosses on their lower face, by which they are fastened to the roof-plate with 1-inch screws passed through the plate into the bosses. Six of these stays are linked by transverse double-hangers to angle-irons riveted to the shell. The hangers have oval holes to allow the fire-box to expand upwards when steam is being raised. The back-plate of the shell is stayed by copper stays tapped into the ends of the girder-stays. The roof of the fire-box is inclined downwards towards the back, to the extent of 2 inches, to prevent the water from leaving the surface when the break is applied, or the engine descending an incline. The fire-bars are of wrought iron, supported on three transverse cast-iron girders. The firing hole is rectangular, fitted with a deflector suspended from above, answering also as a door—adjustable with a handle and rack. A small plate is hinged at the lower side of the doorway, which is turned up to prevent the glare from the fire. The ash-pan is fitted air-tight at the sides and the front. At the back a deflector plate is fixed to throw cinder and ash towards the middle, and a perforated plate is hinged to the bottom, admitting air and retaining cinders.

There are 331 steel flue-tubes, 1½ inches in diameter, No. 14 wire-gauge in thickness, 10 feet 6 inches long between the plates. They are fixed with a Dudgeon mandril at both ends. When brass tubes are used they are bent upwards in the middle of their length about 1½ inches, that they may yield to expansion without forcing them through the plates and causing leakage. They are fixed with thin steel ferules at the fire-box end.

Mr. Stroudley preferred steel tubes to brass tubes, as they cost less than these, and do not wear out.

Steam is taken from the upper part of the dome with a 6-inch pipe, which branches into two smaller pipes in the smoke-box, supplying steam at both ends of the valve-chest. The regulator is an annular disc, turned on a central pivot, covered by a hood, which receives the steam-supply at the upper part of the valve.

The area of the fire-grate is 20.65 square feet. The heating surface of

the fire-box is 112.48 square feet, and that of the flue-tubes is 1372.92 square feet, making together 1485.40 square feet, or 72 times the grate-area.

The boiler is securely bolted to the cylinders and riveted to the plates of the smoke-box, and these are riveted to the side frame-plates.

The weights of the engine and tender are as follows:—

	In Working Order. tons.	cwts.	Empty. tons.	cwts.
Engine:—Leading wheels,	13	16		
Driving wheels,	14	10		
Trailing wheels,	10	8		
	38	14	35	5
Tender, with fuel and water,	27	7	15	7
Total,	66	1	50	12

Tender.—The tender was designed to contain a quantity of water sufficient for the longest run on the Brighton system—89 miles. They can carry 10 tons or 2240 gallons of water, and 2 tons of coal.

The longitudinal frame-plates, one at each side, are of steel, ⅞ inch thick, 14 inches deep, 22 feet 4 inches long, with inside bearings for three axles. The axles are at 7½-feet centres, with 4½-feet wheels. The forward and trailing side springs are laminated; the middle springs are on the Timmis system. The tank is 20 feet long, 6 feet wide, 3½ feet deep outside, with a flat floor. The coping is 7 inches high above the tank.

The weight of the tender, with 10 tons of water and 2 tons of fuel, is 27 tons 7 cwts.

CHAPTER LXVIII.—SIX-COUPLED GOODS LOCOMOTIVE, WITH TENDER.

DESIGNED AND CONSTRUCTED BY MESSRS. BEYER, PEACOCK & CO., MANCHESTER, FOR THE VICTORIAN GOVERNMENT RAILWAYS.

(Cylinders (inside) 17 inches by 24 inches; wheels 4 feet 6½ inches; gauge of way 5 feet 3 inches.)

This engine, figs. 910 to 912, is typical of the ruling practice in goods locomotives of maximum power on English railways—with a difference, the gauge of way being 5¼ feet, or 6½ inches wider than the English gauge. This engine is thus an example of an engine in which there is plenty of room for the lateral development of the parts, sufficient space for which is occasionally felt to be a desideratum in engines constructed for the 4-feet-8½-inch gauge.

The conditions of this engine, as an inside-cylinder engine, differ materially from those of the Midland four-coupled ge 504 and Plate XV., in the presence of a fixed pair of wheels ie absence of a bogie; and the need for an equal distribution of n the three

axles. The loads at the three axles are as follows. The weight of the tender is added:—

	Empty. tons.	cwts.	qrs.	Loaded in Full Order. tons.	cwts.	qrs.
Engine:—Leading wheels,...	9	6	1	10	1	0
Driving do., ...	9	1	0	10	2	0
Trailing do., ...	9	1	2	9	15	0
Total, ...	27	8	3	29	18	0
Tender:—Front wheels,......	3	7	2	7	5	0
Middle do., ...	4	1	0	7	7	2
Hind do., ...	2	18	3	7	3	3
Total, ...	10	7	1	21	15	3
Engine and tender,............	37	16	0	51	13	3

The leading wheels of the engine are 7 feet from the drivers, between the centres; and these are 6½ feet from the trailing wheels —making 13½ feet of wheel-base. The above distribution of weight is practically equal, and it appears by the ordinary rule[1] that the position of the centre of gravity horizontally is 2¾ inches in advance of the driving axle, or about 3 feet 1 inch in advance of the fire-box. The leading wheels being placed so much nearer the centre of gravity in this case than the bogie in the Midland engine, it was necessary, in order that they might not assume an excessive proportion of the weight, that the driving wheels should be placed as far forward as was practicable, consistently with a sufficient length of eccentric-rods and connecting-rods. The former are only 3 feet 7¼ inches long, and the latter 5 feet 4 inches long, or 5⅓ times the length of the crank. A comparison of these lengths, with those of the Midland and the Great North of Scotland Railways, already noticed, is suggestive, and is given on page 586.

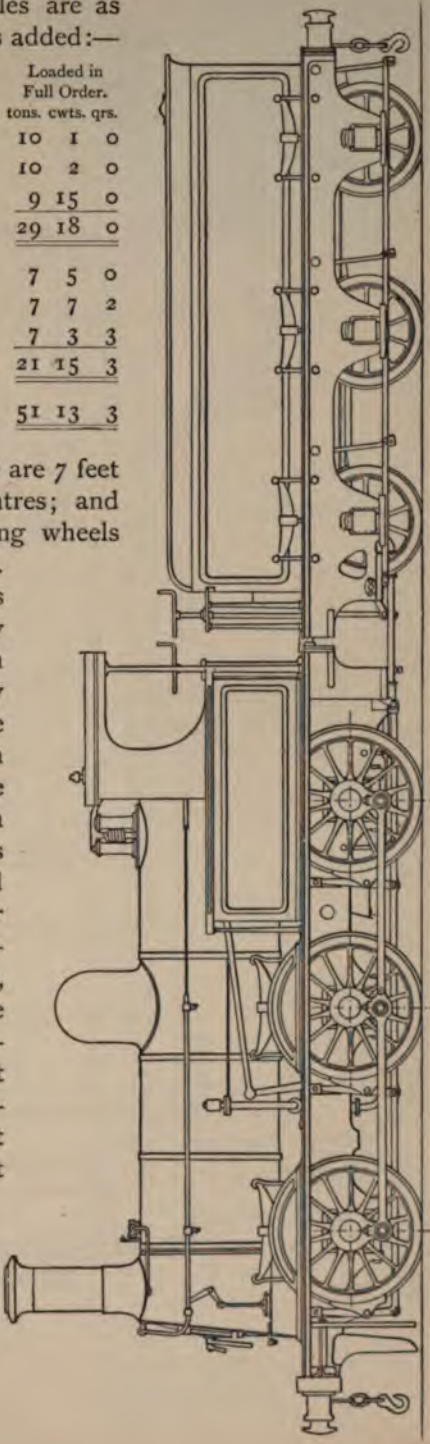


Fig. 910.—Goods Locomotive Engine and Tender, designed and constructed by Messrs. Beyer, Peacock & Co., Manchester. Scale 1/72d.

[1] *Railway Machinery*, page 189.

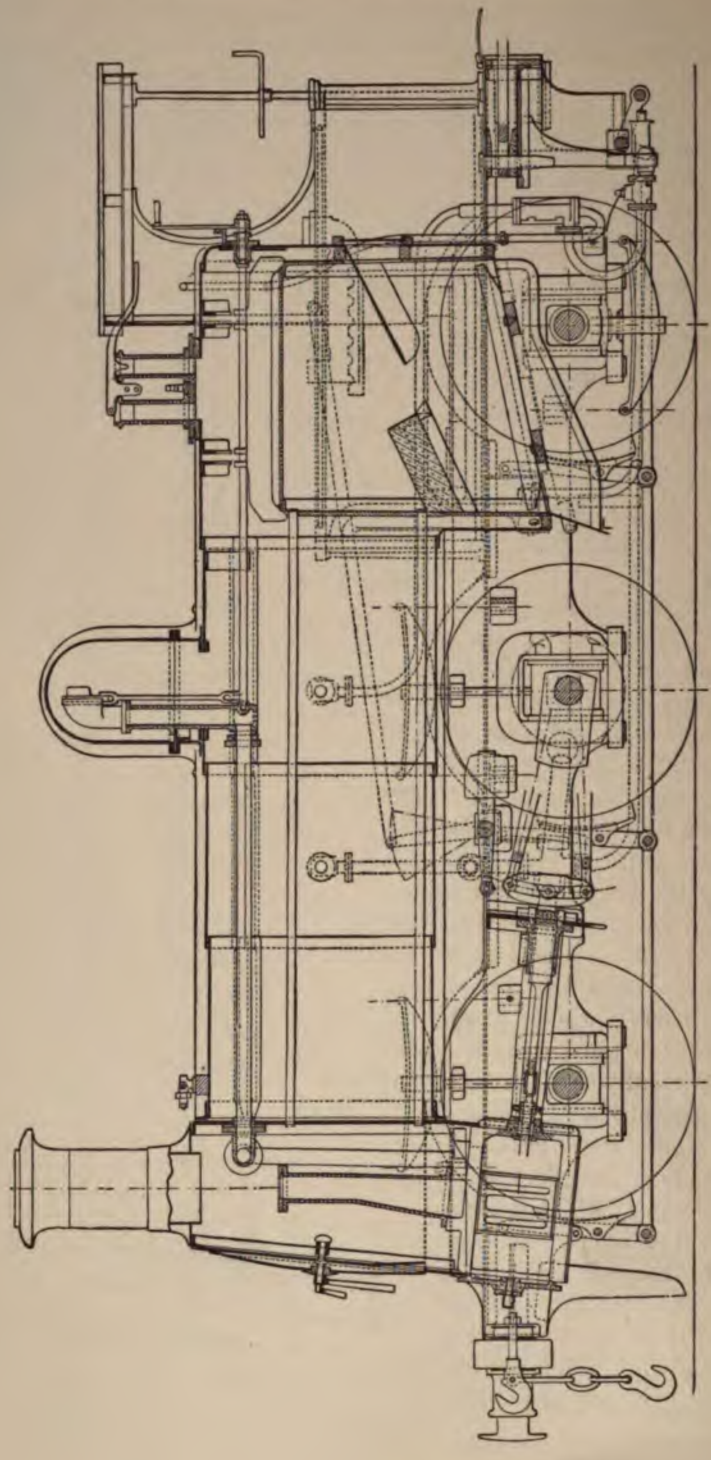


Fig. 911.—Beyer, Peacock & Co.'s Goods Locomotive: Longitudinal Section. Scale 1/40th.

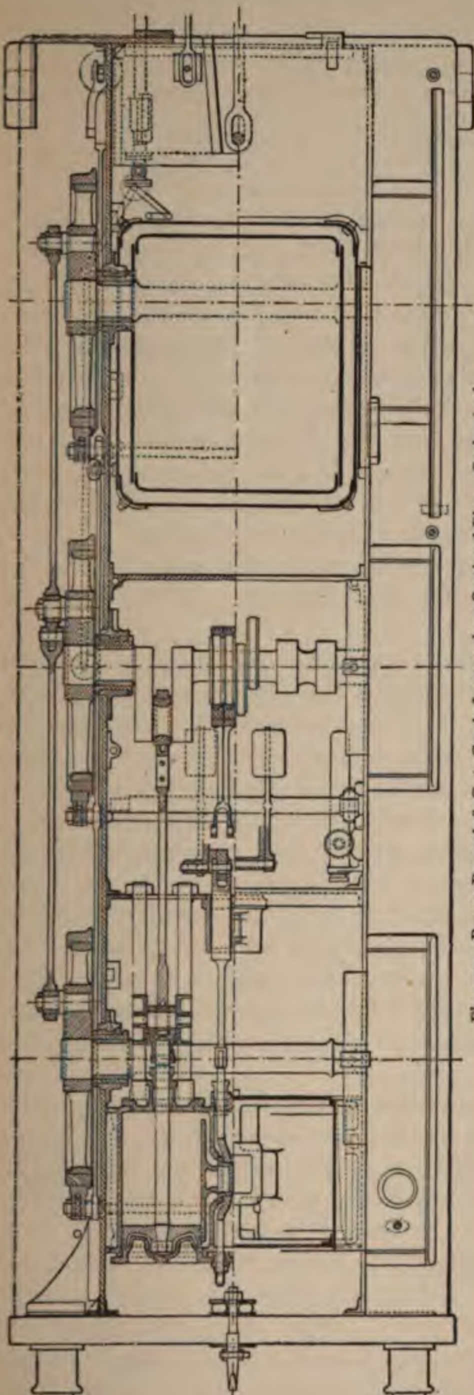


Fig. 912.—Beyer, Peacock & Co.'s Goods Locomotive: Sectional Plan. Scale 1/40th.

To co-operate in equalizing the distribution of weight, the trailing axle is placed under the fire-box, which is sloped upwards towards the back, out of the way. The centre of the axle is 17 inches in advance of the back of the fire-box. The general result of the combination is a nearly equal distribution of the weight of the engine and a compact wheel-base.

The frame is of wrought-iron plates, and consists of two longitudinal plates 1 inch thick, 18 inches deep in the body, 4 feet 6½ inches apart, bound together: 1st, by the pair of cylinders; 2d, by the motion-plate, which is ⅞ inch thick, 23 inches deep, riveted to the side plates with one flange and one 2¾-inch angle-iron with ⅞-inch countersunk rivets; 3d, by a tie-plate 1¼ inches by 5 inches deep, 18 inches behind the driving axle; 4th, by the back end beam, 1¼ inches thick, 12 inches deep, 7¼ feet long. The side frame-plates are 22 feet 7⅝ inches long, and the upper edges are 4 feet 4¾ inches above the level of the rails. The buffer-beam, of wood, 6 inches by 16 inches deep, 7 feet 11 inches long, is fastened to the side plates with angle-irons and gusset-plates. The guides for the axlebox are steel blocks. The draw-hook is bedded on an india-rubber ring at the inside of the buffer-beam. The buffers are 6¼ feet apart, and range at a height of 3¼ feet above the level of the rails.

The boiler is of Lowmoor

	Connecting-rods.	Eccentric-rods.	Centre of Gravity in advance of Driving Axle.
Midland, ...	6 feet 2¾ in. or 5.75 cranks.	4 feet 3⅞ in.	9.90 inches.
Great North,..........	6 „ 1½ „ or 5.65 „	5 „ 1 „	9.42 „
Victorian, ...	5 „ 4 „ or 5.33 „	3 „ 7¼ „	2.75 „

iron. The barrel is 10½ feet long, 4 feet ¼ inch in diameter, in three rings of 7/16-inch plates, telescopically lapped—the ring of largest diameter being joined to the firebox-shell. The firebox-shell is of ½-inch plates in three covering plates riveted together. It is 5 feet 1 inch long, 4 feet 3 inches wide, outside; and the upper part is struck with a radius of 2 feet 1½ inches. The steam-dome is placed on the barrel of the boiler, on the ring of plate adjoining the firebox-shell. It is 19 inches in diameter, and 33 inches high above the boiler. It is of ⅝-inch plate welded into a solid forging. The opening in the barrel-plate is 16 inches in diameter, and is fortified by two wrought-iron rings riveted to the plate, one above and one below the opening. The chimney is 15 inches in diameter.

Seams are made with ¾-inch rivets, at 1¾ inches and 1⅞ inches of pitch. The plates lap 2½ inches for single-riveting, and 3¾ inches for double-riveting.

The steam-pipe in the boiler is of copper, No. 10 wire-gauge in thickness, 3½ inches in diameter, finished with a cast-iron upright pipe leading from the upper part of the dome. This pipe terminates in a flat face containing three ports, each 4 inches wide, ⅞ inch high, covered by a two-ported brass valve, which is shifted vertically for admitting or shutting off steam. The ports of the valve are hooded in such a manner that steam from the dome does not enter them directly, but approaches from the entrance to the hood, which is at the top of the valve.

Two 3½-inch safety-valves are fitted on two brass standards fixed on the top of the firebox-shell, 9½ inches apart between centre-lines. The valves take a horizontal bearing on the seats, each surface of contact being an annulus 1/16 inch wide. They are held down by a helical spring of ⅞-inch round steel, coiled to a diameter of 4½ inches externally, with a cross-bar.

The fire-box is of ½-inch copper plates, and is 4½ feet long, 3 feet 8 inches wide inside, 4¾ feet high at the front, sloped to 3¾ feet high at the back. The tube-plate is thickened to ⅞ inch at the tubes. The water-spaces round the fire-box are 2½ inches wide at the bottom, expanding to 3¼ inches at the top. The fire-box is joined to the shell at the bottom with a solid "foundation-ring," 2½ inches wide, 2¼ inches deep. It is stayed to the shell with ⅞-inch stay-bolts, averaging 4 inches apart between centres. It is also stayed to the barrel with eight palm stay-bolts. The roof is stayed with eight bars of wrought iron 1½ inches thick, 6 inches deep, the four middlemost bars being linked to the upper part of the shell at two points in each. The upper pin-holes of the links

are slotted to admit of contractile movements. The doorway is oval, 15 inches wide, 12 inches high.

There are 189 solid-drawn brass tubes, 1⅞ inches in diameter outside, in horizontal rows, and at 2½-inch centres, or ⅝-inch clear intervals; 10 feet 9½ inches long between the plates. The tubes are not horizontal, but are inclined upwards towards the smoke-box, at the rate of 1 inch in the length, in order to keep them parallel to the telescopic bottom of the barrel. They were fixed by being expanded into the tube-holes in the tube-plates, and fastened with steel ferules at the fire-box ends. The back plate of the firebox-shell is stayed to the smoke-box tube-plate with seventeen 1⅛-inch tie-rods.

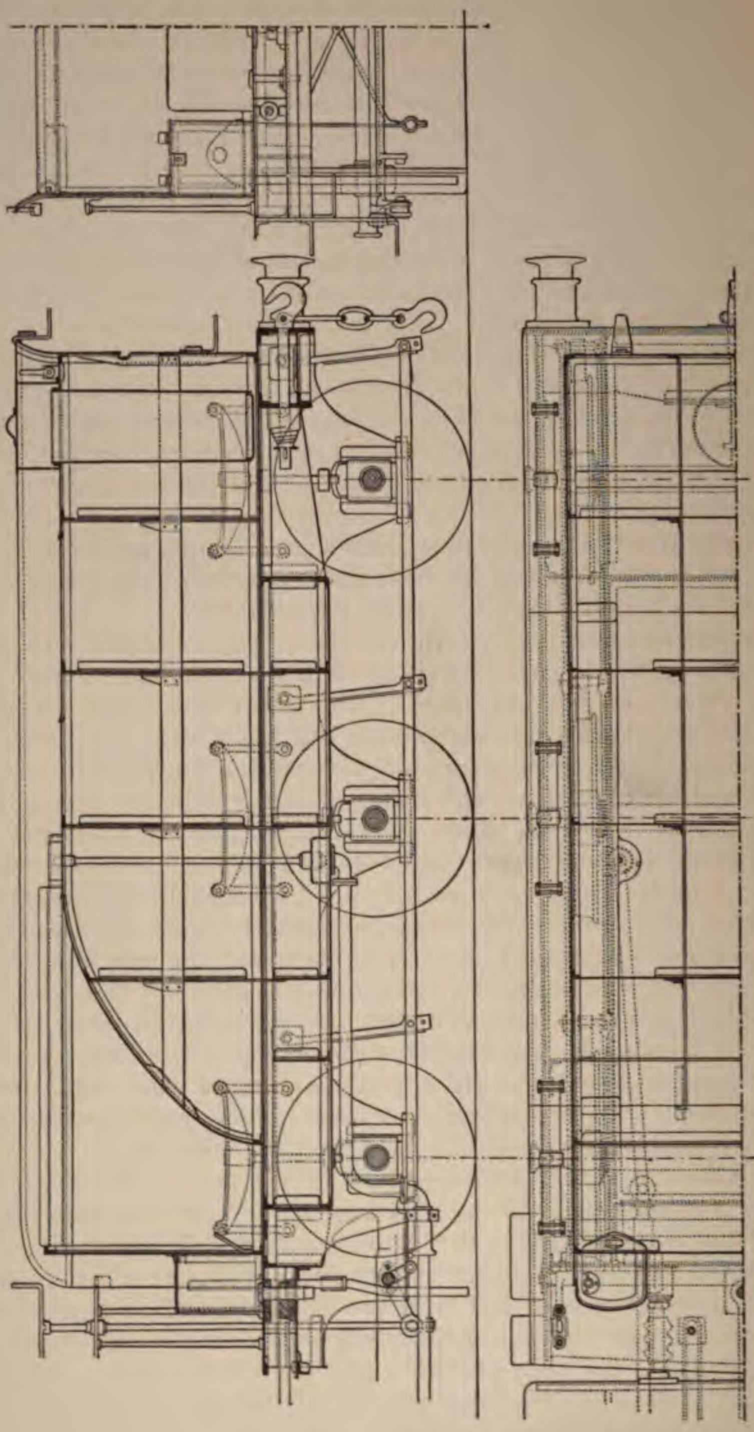
The fire-box is fitted with a slanting fire-brick arch extending 19½ inches from the tube-plate, and a slanting scoop at the doorway projecting 28 inches in the fire-box, leaving a free-way of 12 inches between the arch and the scoop for the meeting and mixing of the combustible gases and the air from the doorway. The supply of air is regulated by a pair of sliding doors.

The area of fire-grate is 16½ square feet, the heating surface of the fire-box is 71.3 square feet, and that of the flue-tubes is 1000 square feet; together, 1071.3 square feet, or 65 times the grate-area.

The cylinders are 17 inches in diameter, with a stroke of 24 inches, placed at a distance apart of 30½ inches between their centre-lines, forming the valve-chest between them. They are 1 inch thick. They are fastened to the side frame-plates and to each other with 1-inch bolts and nuts. The front covers are fastened with twelve 1-inch bolts and nuts, pitched at about 5¾ inches. The steam-ports are 13½ inches by 1⅜ inches, or $^1/_{12.5}$ part of the cylinder-area. The exhaust-ports are 3½ inches long, or $^1/_5$th of the cylinder-area. There are two pairs of guide-bars to each cylinder, 3 inches wide, bolted to the back cover and to the motion-plate. The piston is of cast iron in one piece, fastened on the taper end of the rod with a nut. It has two cast-iron packing rings ⅜ inch thick, ¾ inch wide, turned tight to gauge of 17 inches in diameter, and then split. The rod is 2¾ inches in diameter, of steel, cottered into the crosshead for a depth of 5½ inches, slightly tapered, with a cotter ⅝ inch thick, averaging 2⅛ inches wide, rounded at the edges, secured by a small cotter through the lower end. The crosshead is of steel, in one piece, forked, with a gudgeon 3 inches in diameter, offering a journal 3 inches long.

The connecting-rod is of wrought iron, 5 feet 4 inches long, or 5.33 times the length of the crank; having a bearing 3 inches in diameter, 3 inches long at the crosshead end, and a bearing 7 inches in diameter, 4 inches long, for the crank-pin. At each end the rod is made with a butt and strap, fastened together at each end with two bolts and nuts, 1⅛-inch for the small end, 1¼-inch for the large end, with a cotter at each end for tightening the brasses. The body of the rod is of uniform thickness, 2 inches; by 4¼ inches deep at the larger end, tapered to 3 inches at the smaller end.

The coupling-rods are of wrought iron, 6½ feet long, having bearings



Figs. 913.—Tender for Goods Locomotive, by Messrs. Beyer, Peacock & Co., Manchester: Vertical Sections and Plan. Scale 1/40th.

3 inches in diameter, 3 inches long, in solid-forged ends, with brass bushes, ⅞ inch thick. The body of the rods are 1¼ inches thick, 3½ inches deep.

The axles are of cast steel, 6⅜ inches in diameter, with 6¾-inch journals, which are 9 inches long for the driving axle, and 8 inches long for the leading and trailing axles. In the wheels they are 8 inches in diameter. The crank-pins are 7 inches in diameter, 4 inches long; the cheeks or webs are 4 inches thick by 11 inches wide.

The wheels are 4 feet 6½ inches in diameter, of solid-welded wrought iron, with cast-steel tyres, notched on to the rims.

The axleboxes are of wrought iron, case-hardened, with brass bushes and keeps. The leading axleboxes are fitted with double-inclined-plane sliding covers. The boxes have a lateral play of ⅜ inch each way from the central position; and the inclined-plane bearing surfaces tend to restore the axleboxes to their central position when moved from it on curves.

The side springs, one to each axlebox, are of plates 4 inches wide. They are 3 feet in span, and are placed above the leading and driving axleboxes, and below the trailing axleboxes.

The valve-gear is the ordinary shifting-link motion. The eccentrics are 14¾ inches in diameter, 2½ inches wide, with a throw of 5¾ inches. The straps are of wrought iron, lined with brass. The eccentric-rods are of wrought iron, 3 feet 7¼ inches long. The expansion-link is 16 inches long between centres, on 1½-inch pins, and is 2¼ inches thick; the groove is 2½ inches wide, and the die a movable block 3½ inches long. The block is centred on the valve-spindle, which is made up to 4¼ inches in diameter to work in a brass guide 12 inches long, fastened to the motion-plate. The slide-valves have ⅞ inch of lap, fully ⅛ inch of lead, and fully 3⅞ inches of maximum travel.

The blast-pipe is of cast iron, 5 inches in diameter, of ½-inch metal, finished with a cast-iron nozzle-piece, having a 4-inch orifice, at a level 1¼ inches above the uppermost flue-tubes, and 17 inches below the entrance to the chimney.[1] The nozzle-piece is surmounted by a ⅝-inch ring steam-pipe or "blower," perforated for the escape of steam in small jets up the chimney, to maintain a draught when the engine is not working.

The engine is fitted with a combined steam-and-hand break, acting on all the wheels. There are two injectors for feeding the boiler with water.

Tender.—The tender, fig. 910, page 583, and figs. 913, annexed, is constructed to hold 2000 gallons, or 320 cubic feet, or about 9 tons of water, with 120 cubic feet of space for fuel, or about 2⅔ tons of coal, allowing 45 cubic feet per ton; together 11⅔ tons, which is a little more than is allowed for in the official weight given, page 583. The frame is 18 feet 3½ inches long, 6 feet 11½ inches wide, outside measure. It consists of two main longitudinal plates 1 inch thick, 12 inches deep, and two inner

[1] The late Mr. Peacock was the first who experimentally investigated the question of the most effective level of the blast orifice, consistent with the largest diameter. The results of the experiments, with his deductions, are fully detailed in *Railway Machinery*, page 134.

longitudinal plates or stretchers, ½ inch thick; with end transverse plates and hind plate of the well, also ½ inch thick.

The tank is 14 feet long, 6 feet ½ inch wide outside, 3½ feet high inside, with a well. The top of the coping is 4¼ feet above the frame. The thickness of the tank-plates are as follows:—Top, No. 6 wire-gauge; bottom, ¼ inch; outside and back, No. 7 wire-gauge; front of well, ⅜ inch; sides and back of well, ½ inch. The six wheels are 3 feet 6½ inches in diameter, at 6 feet apart between centres, making 12 feet of wheel-base. The axles have journals outside the wheels, at a distance apart on the axle of 6 feet 8½ inches between mid-lengths. The side springs, one over each journal, have a span of 30 inches; and are of plates 4 inches wide. A hand-break is fitted, applied to each wheel. The break-screw is 1⅜ inches in diameter, ⅜ inch pitch.

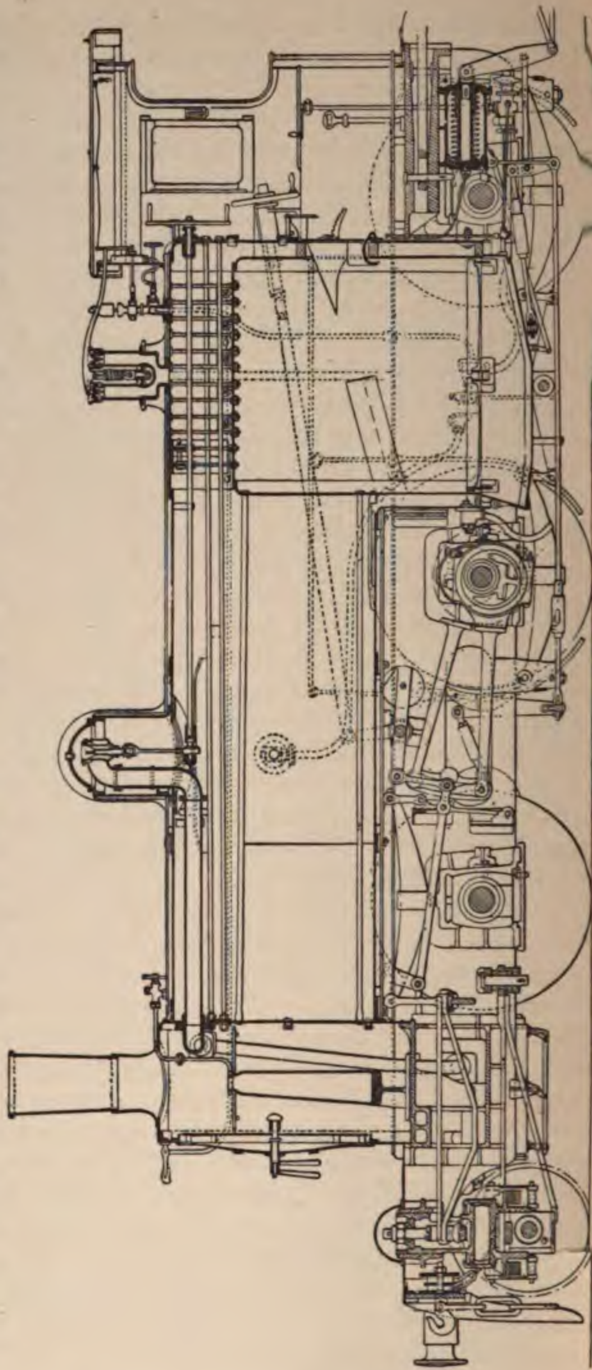


Fig. 914.—Six-coupled Goods Locomotive, Mogul type, for the Great Eastern Railway. Constructed by Neilson & Co. Longitudinal Section. Scale 1/30th.

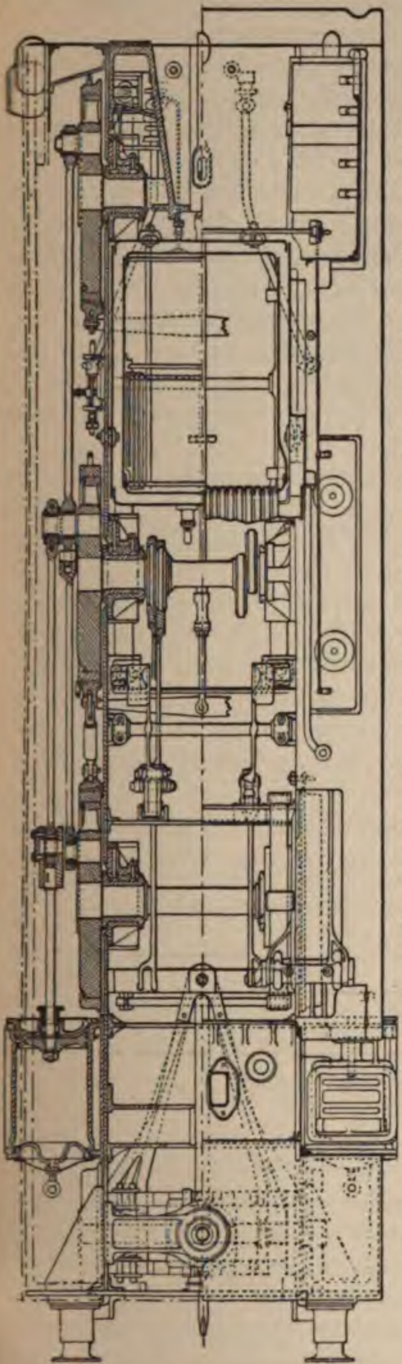


Fig. 915.—Six-coupled Goods Locomotive, Mogul type, for the Great Eastern Railway. Constructed by Neilson & Co.: Sectional Plan. Scale 1/50th.

CHAPTER LXIX.—SIX-COUPLED GOODS LOCOMOTIVE, MOGUL TYPE.

DESIGNED BY MR. MASSEY BROMLEY FOR THE GREAT EASTERN RAILWAY.

(Cylinders, outside, 19 inches by 26 inches; wheels 4 feet 10 inches; gauge of way 4 feet 8½ in.)

A locomotive of the Mogul type, manufactured by Messrs. Neilson & Co. for heavy coal traffic between March and London, is shown in figs. 914 and 915, having six-coupled wheels and a pony-truck, with horizontal outside cylinders. The cylinders are 19 inches in diameter, with a stroke of 26 inches; 6 feet 8 inches apart between centre-lines, with horizontal valve-faces on the top. The slide-valves are worked by an ordinary link-motion, with intermediate rocking shafts. The coupled wheels are 4 feet 10 inches in diameter, on a wheel-base of 15 feet 9 inches. The pony-wheels are 2 feet 10 inches in diameter, placed at 7 feet 5 inches from the leading coupled wheels, between centres, and making a total wheel-base of 23 feet 2 inches. The weights of the engine and the tender are as follows:—

	Empty.		In Working Order.	
	tons.	cwts.	tons.	cwts.
Leading coupled wheels	11	12	13	6
Driving wheels...........	11	12	13	6
Trailing coupled wheels	11	12	13	6
Adhesion weight.........	34	16	39	18
Pony-wheels	7	11	7	19
Total engine..............	42	7	47	17
Tender	17	1	32	4
	59	8	80	1

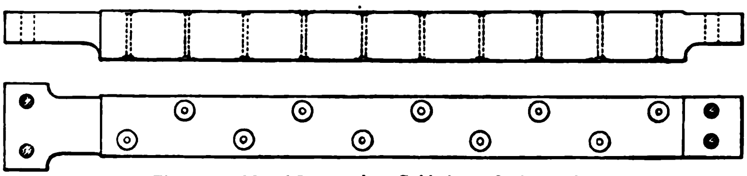
The weights on the driving and trailing wheels are equalized together by an intermediate lever at each side, linked to the ends of the side-springs; and the leading coupled and pony wheels are equalized together. The

longitudinal frame-plates are 1⅛ inches thick, 2 feet 8½ inches deep, 4 feet 2 inches apart. Their total length is 27 feet 9 inches.

The barrel of the boiler is 11 feet 5 inches long, 4 feet 5 inches in diameter inside, in three rings of plates, butt-jointed, with welts or covering plates. The firebox-shell is of 9/16-inch plates, except for the back, which is ½ inch thick. It is flush with the barrel, for the upper half circle. It is 6 feet long, 4 feet 1 inch wide outside. The fire-box has 17.8 square feet of fire-grate, and 102.24 square feet of heating surface. There are 240 flue-tubes 1¾ inches in diameter at the fire-box end, pitched at 2⅜ inches; 1⅞ inches at the smoke-box end, pitched at 2½ inches. They make 1291.2 square feet of heating surface, or, together with the fire-box, 1393.44 square feet, which is about 79½ times the grate-area. The roof of the fire-box is stayed to the shell, with 15/16-inch stay-bolts, at 4⅜-inch centres. The fire-box is fitted with a brick arch and a door-scoop or deflector, for smoke prevention.

A 21-inch steam-dome is fixed on the centre-plate of the barrel. The top of the dome is a cast-iron segment of a sphere, bolted to the body of the dome. The steam-pipe within the boiler is of iron, 4½ inches in diameter, 3/16 inch thick. It takes the steam from the top of the dome with a double-beat valve. The branch steam-pipes to the cylinders are of copper, 3½ inches in diameter, 3/16 inch thick. A pair of 3-inch direct-action safety-valves is fixed on the firebox-shell, held by a helical spring pinned to a crosshead, which takes a bearing on each valve. The centres of the valves are respectively 4½ inches and 49/16 inches from the centre-line of the spring, the odd 1/16 inch being added by way of compensation for the overhung hand-lever.

The cylinders are of 1-inch metal. There is but one guide-bar to each cylinder, figs. 916, placed above the crosshead, figs. 917, which is one with

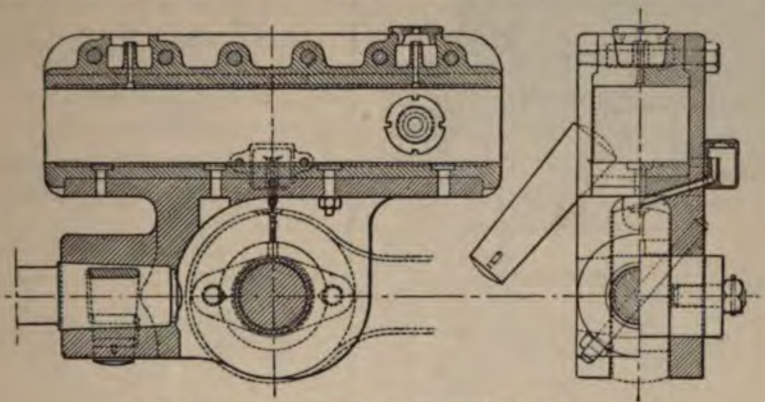


Figs. 916.—Mogul Locomotive: Guide-bar. Scale 1/16th.

the slide by which the bar is embraced. The connecting-rods are 7 feet 1½ inches long, or about 6½ times the length of the crank. The link-motion is connected by a wyper-shaft to each valve-spindle.

The pony-truck is pivoted to the frame at a point in the main centre-line, 5 feet 7½ inches behind the axle, by means of a triangular attachment, which connects the pivot or pin with the axleboxes. The load is applied to an intermediate point of an equilibrating bearer, fig. 918, in the central line of the engine, one end of which is supported on a transverse lever, suspended by the ends from the hinder ends of the side-bearing springs of the trailing coupled axle, and the other end is carried in a suspending link

which is hung from a central cylindrical casting, through which the load is transmitted to the axle. This casting bears on a cylindrical mass of india-



Figs. 917.—Mogul Locomotive: Crosshead and Slide. Scale 1/10th.

rubber, 4 inches thick, 15 inches in diameter, seated on a cast-iron bed which rests on a pair of transverse laminated springs—each end of which is suspended from a pair of pins fastened to the top of the axlebox. According as the truck sways to one side or the other, the suspending link is deflected laterally, and pivots of one pin or the other, in the manne of a double-pivoted gate; and there is simultaneously a tendency to resume, by gravitation, the position of central alignment. The suspending links are 10 inches long, and the alternative pivots are $3\frac{1}{4}$ inches apart between centres.

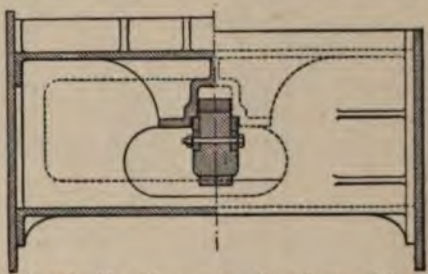


Fig. 918.—Mogul Locomotive: Cross Section of Pony Frame and Equilibrating Lever. Scale 1/24th.

The price of the engine was £1950, or £46 per ton of weight; that of the tender was £450, or £26, 8*s.* per ton; and that of the engine and tender together was £2400, or £40, 8*s.* per ton.

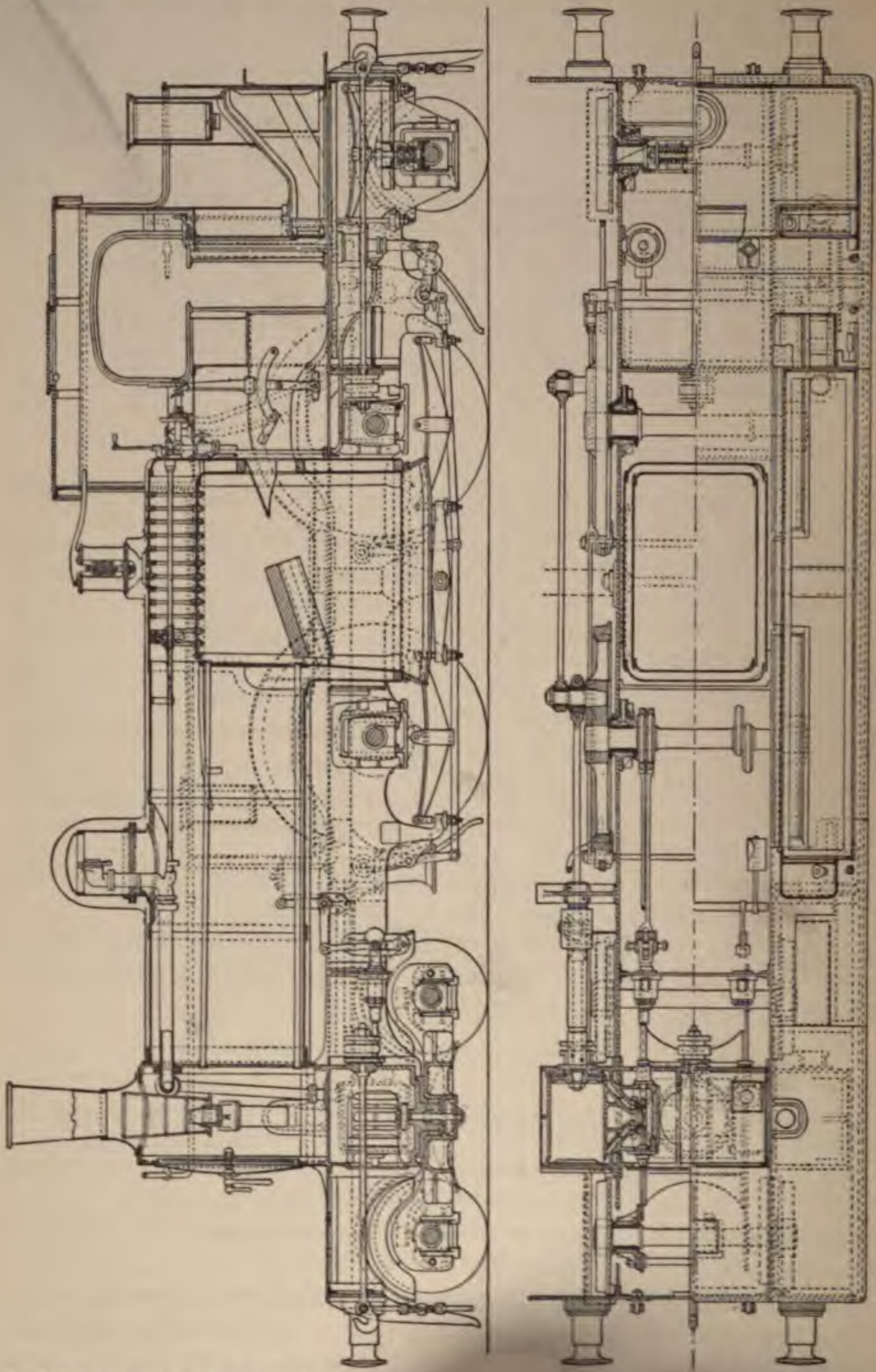
Chapter LXX.—TEN-WHEELED TANK LOCOMOTIVE.

CONSTRUCTED BY MESSRS. SHARP, STEWART, & CO., MANCHESTER, FOR THE LONDON, TILBURY, AND SOUTHEND RAILWAY.

(Cylinders 17 inches in diameter, stroke 26 inches; driving wheels 6 feet 1 inch in diameter; gauge of way 4 feet $8\frac{1}{2}$ inches.)

This locomotive, figs. 919, has been described as a "universal machine," having been designed to combine in one type of engine the capability for working the heaviest goods and cattle trains, for running at express speed with passenger trains, for stopping and starting quickly with ordinary

passenger trains, for running equally well either end foremost, as a "double-



Figs. 919.—Ten-wheeled Tank Locomotive, London, Tilbury, and Southend Railway. Constructed by Sharp, Stewart, & Co. Scale 1/60th.

ender," with freedom and safety a' ro 'requent curves

of the line. The need for running either end foremost arose specially from the triangular approach to Tilbury Station, which is on one side of the main line, and into and out of which trains go and come reversely.

The engine is placed on four coupled wheels, 8½ feet apart between centres, a four-wheel bogie at the leading end, the pivot of which is 10 feet 4 inches apart from the driving axle, between centres; and a pair of radial-axle wheels 7¼ feet behind the hind coupled wheels. The wheel-base thus extends to 29 feet 4 inches; but the fixed or parallel-axle base does not exceed 8½ feet. The weight of the engine empty is 44½ tons. The distribution of the weight, in working order, is as follows:—

	Tons.	Cwts.	Qrs.
Bogie	15	18	0
Driving wheels	16	0	2
Hind coupled wheels	16	0	2
„ trailing axle, radial	8	2	3
Total	56	1	3

This is a very fair distribution of weight—16 tons on each pair of drivers, and half of that, or about 8 tons, on each pair of carrying wheels.

The longitudinal frame-plates are of Landore steel, 1 inch thick, 18½ inches deep, 4 feet apart, bound together with two 1¼-inch buffer-plates and other plates, and the bogie attachments. They are 32 feet 11 inches in length. The total length of the engine over the buffers is 36 feet 8 inches.

The barrel of the boiler is of ½-inch Yorkshire iron plates, butt-jointed, with covering plates; 4 feet 1 inch in diameter inside, 10½ feet long. The firebox-shell is of ½-inch plates, except the front plate, 9/16 inch; 6 feet long, 3 feet 10½ inches wide, outside. The fire-box is of ½-inch copper plates, except the tube-plate, ¾ inch. It is 5 feet 43/16 inches long, 3 feet 2¾ inches wide, inside, at the bottom. There are 200 flube-tubes, 1⅝ inches in diameter, pitched at 2½ inches, 10 feet 10¼ inches long between the plates. The grate-area is 17.25 square feet. The heating surface of the fire-box is 97 square feet; of the flue-tubes, 923 square feet; together, 1020 square feet, or 59.1 times the grate-area. The chimney is 15½ inches in diameter at the bottom. The tanks can hold 1300 gallons, or 208 cubic feet, or 5.80 tons of water. There is capacity for 2¼ tons of coal, heaped. The working pressure is 160 lbs. per square inch.

The cylinders are outside, lodged between the wheels of the bogie, at each side. They are 17 inches in diameter, with a stroke of 26 inches, 6¼ feet apart between centre-lines. The piston-rods are 3 inches in diameter; the crossheads are each attached to a single guide-bar above it; the connecting-rods are of Yorkshire iron, 6¼ feet long, or 5.77 times the length of the crank. The axles are of crucible cast steel. The driving and coupled axles are 6½ inches in diameter at the middle, 7 inches at the journals, which are 8 inches long; 8½ inches in the wheels. The driving wheels are 6 feet 1 inch in diameter, with tyres 5½ inches wide

The crank-pins are of Yorkshire iron, case-hardened at the journals. The coupling-rods are of Bessemer steel.

The bogie is on four wheels 3 feet 1 inch in diameter, 6½ feet apart between centres; and two axles 5½ inches in diameter at the middle, with 6-inch journals 9 inches long. The bogie is on Mr. W. Adams' system, being capable of side-play to the full extent of 2½ inches, controlled by two helical springs acting horizontally, one at each side of the central bearing, set with the degree of initial compression requisite to bring back the bogie to its central position, after having deviated when running on a curve. The springs deflect 1¼ inches per ton of stress. Each spring is prevented from following up any lateral movement of the bogie, from its own side. Thus, the bogie is free to return to the central position from the other side by the impulsion of the spring on that side, without opposition from the other spring.

The radial wheels and axle, fig. 920, at the other end of the engine, are of the same dimensions as those of the bogie. They have a lateral range of 2 inches, controlled by helical springs as in the bogie. The axle-boxes and their guides are struck to a radius of 5 feet 3½ inches.

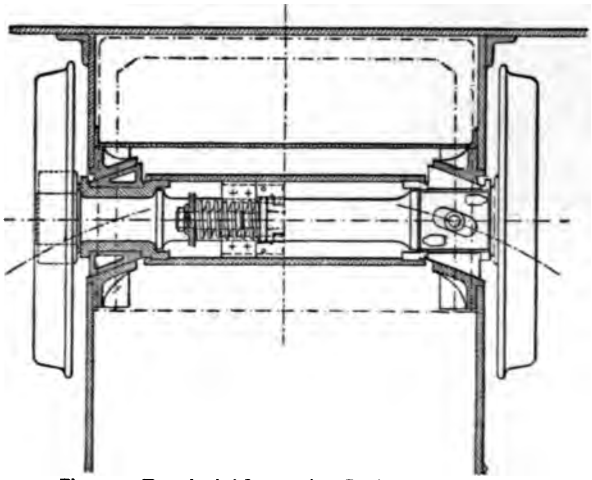


Fig. 920.—Ten-wheeled Locomotive: Radial Wheels and Axle. Scale 1/24th.

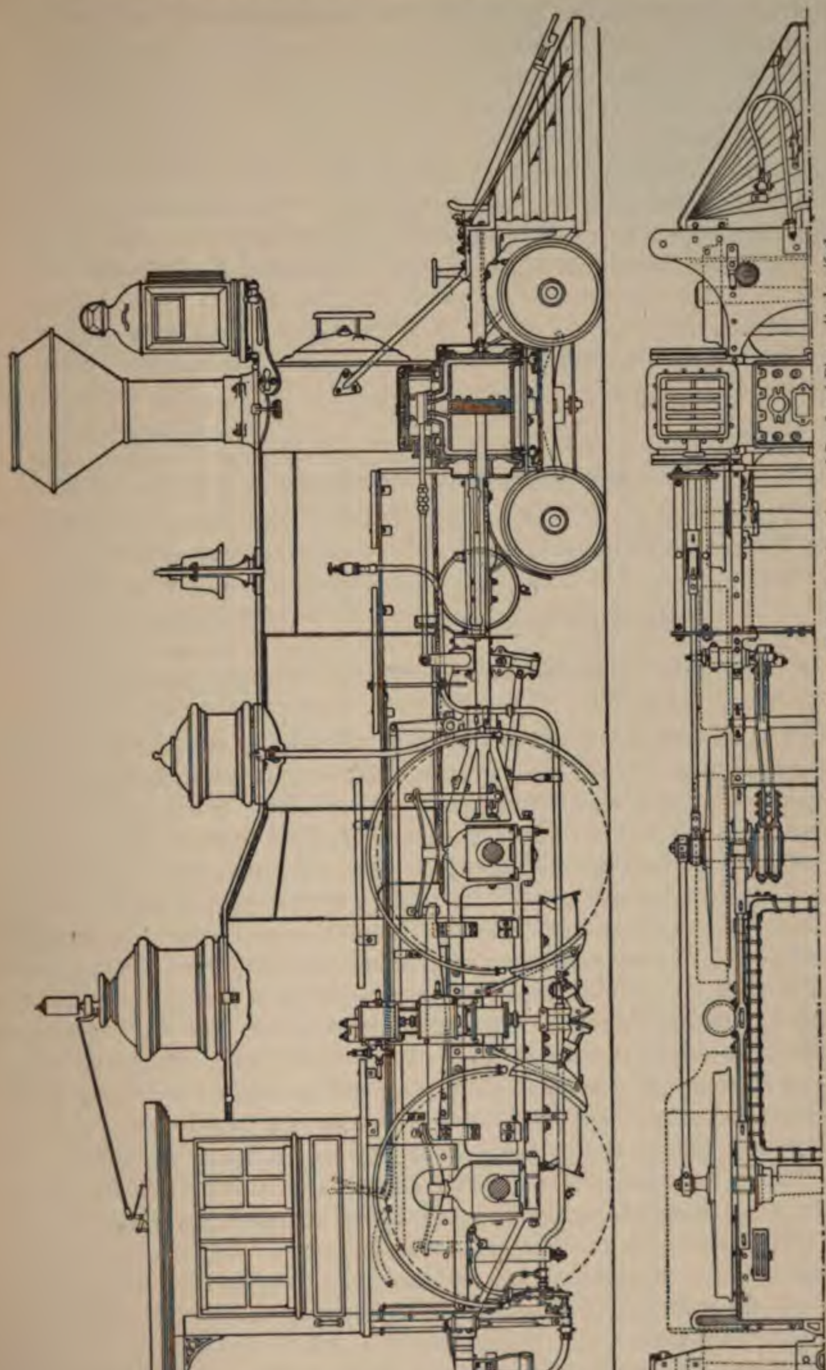
The side bearing springs for the driving and coupled axles are 4½ feet in span, having fourteen ½-inch plates 5 inches wide, equilibrated by an intermediate lever. Their deflection is at the rate of .38 inch per ton of load. The bogie springs have a span of 4 feet, and have twelve ½-inch plates, 5 inches wide, deflecting .47 inch per ton of load. The trailing springs are 3½ feet in span, and have nine ½-inch plates, 4½ inches wide.

CHAPTER LXXI.—FOUR-COUPLED-WHEEL PASSENGER LOCOMOTIVE.

DESIGNED BY MR. GODFREY RHODES, FOR THE CHICAGO, BURLINGTON, AND QUINCY RAILROAD.

(Cylinders 18 inches in diameter, stroke 24 inches; wheels 5 feet 9 inches; gauge of way 4 feet 8½ inches.)

This locomotive, figs. 921, ' ystem universally followed in



Figs. 921.—Passenger Locomotive for the Chicago, Burlington, and Quincy Railroad: Elevation and Sectional Plan. Scale 1/60th.

America, having outside cylinders, four-coupled driving wheels, behind, and a four-wheel truck or bogie in front. The gauge of the way is 4 feet 8½ inches. The cylinders are horizontal, alongside the smoke-box and between the wheels of the bogie. The coupled axles are 8½ feet apart between centre-lines; the bogie-axles are 5 feet 8 inches apart, and the pivot of the bogie is 11 feet 2¼ inches from the driving-axle. The wheel-base of the engine is 22 feet 6¼ inches long; the total wheel-base of the engine and tender is 44 feet 9 inches, and the length over all is 56 feet 10 inches. The weight in working order is distributed as follows:—

	Lbs.		English tons
Driving wheels	27,000	or	12.05
Trailing wheels, coupled	27,500	„	12.28
Total driving weight	54,500	„	24.33
Bogie	28,300	„	12.63
Total weight of engine in working order	82,800	„	36.96
Tender, empty	24,183	„	10.80
Water, 2750 gallons (8⅓ lbs.)	22,917	„	10.23
Coal	14,550	„	6.50
Total weight of tender, full	61,650	„	27.53
Total weight of engine and tender, in full working order	144,450	„	64.49

According to this excellent distribution of weight, two-thirds, in round numbers, is available for driving; and the weight at each bogie-axle is one-half of that on each driving-axle.

The frame is the bar-frame generally used in American locomotives, of which the frame originally designed and employed by the late firm of Bury, Curtis, & Kennedy, of Liverpool, was the prototype. It consists literally of two longitudinal framed structures, one at each side, connected and stiffened by transverse bars and plates. Each structure is in two pieces bolted together. The backward piece has an upper and a lower member, welded together with the axle-guards; merging, towards the front, in the forward piece, which is a single bar, to which the cylinder is fastened. These elementary bars are 3 inches wide, from end to end of the engine. The upper member at and between the axle-guards is 4 inches deep; the lower member 2¼ inches deep; they are 15⅞ inches apart vertically. The single bar at the cylinders is 4 inches deep. The lower ends of each axle-guard are connected together by intermediate struts and through bolts and nuts. The side frames are 3 feet 8 inches apart.

The boiler is of steel plates, and is of the "wagon-top" description, in which the firebox-shell is considerably higher than the barrel, and is joined to it by a long-slope plate. The barrel is 4 feet 1½ inches in diameter inside, about 11¼ feet long, of ⅜-inch plates. The seams are lap-jointed, single-riveted transversely, double-riveted longitudinally. The firebox-shell is 6 feet 8⅜ inches long, 3 feet 6¾ inches wide, outside. The chimney is

17 inches in diameter, and it stands 14 feet 8 inches high above the level of the rails. The fire-box is of steel, 3/8 inch thick; 6 feet long, 2 feet 11¼ inches wide, inside, at the bottom, widened at the upper part to take in flue-tubes. The water-spaces are 3 inches wide. The tube-plates are of ½-inch steel plates. The crown of the fire-box is strengthened with fourteen transverse stays. The steam-dome, placed on the firebox-shell, is 28 inches in diameter, 24 inches high. There are 189 flue-tubes, 2 inches in diameter outside, 11 feet 5 3/8 inches in length between plates, placed at 2 5/8 inches pitch. A rocking fire-grate is employed, having fire-bars 1 3/8 inches thick, with ½-inch air-spaces. The area of the fire-grate is 17.7 square feet; the heating surface of the fire-box is 102.1 square feet; of the flue-tubes, inside, 958.2 square feet; together, 1060.3 square feet, or 60 times the grate-area. The working steam-pressure in the boiler is 145 lbs. per square inch.

The cylinders are laid with their horizontal centre-lines 2 inches above the level of the centre-line of the driving-axle. They are 18 inches in diameter, with a stroke of 24 inches; 1 1/8 inches thick. Steam is brought to the cylinders by a 5½-inch pipe in the boiler, branched in the smoke-box to each cylinder, with a sectional area of 16 square inches. The valve-face is horizontal, above the cylinder. The steam-ports are 1¼ inches by 16 inches: 20 square inches in area, $^1/_{12.72}$ part of the cylinder-area. The exhaust-port is 2¼ inches by 16 inches; 36 square inches in area, $^1/_{7.1}$ part of the cylinder-area. There are two blast-nozzles, one to each cylinder, 3¼ inches in diameter, from which the steam is exhausted into a petticoat-pipe. The piston is 4½ inches thick, with a 3-inch piston-rod. Each crosshead is formed with two lateral slide-blocks, which work in two pairs of guide-bars. The connecting-rod is 7 feet 3½ inches long, or 7.3 times the length of the crank. It is formed with butts and straps bolted together, and cotters. The crosshead bearing is 2¾ inches in diameter, 3 inches long; the crank bearing is 4 inches by 4 inches. The coupling-rods are of double-flange or H section, with 3½-inch bearings, 3 1/8 inches long. The driving wheels are 5 feet 9 inches in diameter, of cast iron, with steel tyres. The driving and coupled axles are 8½ feet apart; they have 7-inch journals, 7½ inches long; they are 6½ inches in diameter at the middle, and 6 7/8 inches in the wheels, in which they have 7¾ inches length of bearing. The truck-wheels are of cast iron, with steel tyres, 30 inches in diameter; the axles are 5 feet 8 inches apart, they are 4¼ inches at the middle, 5 inches at the journals, which are 9 inches long; and 5 inches in the wheels, with 8 inches length of bearing in them. The side bearing springs for the driving and coupled axles, have 2 feet 10 inches of span, and consist of ten 3/8-inch "leaves" or plates, 3½ inches wide. They are connected by equilibrating beams. The bogie-springs, one at each side, in a cradle, have 3 feet 4 inches of span, and consist each of fourteen ¾-inch leaves 4 inches wide.

The slide-valves have 7/8 inch of lap outside, and $^1/_{16}$ inch inside; $^1/_{16}$ inch of lead, in full-gear; and a maximum travel of 5 inches. The

shifting link motion is employed, having eccentrics of 5 inches throw; eccentric-rods 4 feet 10⅛ inches long; and links of the same length of radius, and 2½ inches wide. The motion is communicated to the valves through rocking shafts. There is a history attached to the eccentrics. Formerly, they and their straps were only 2¾ inches wide, and were a constant source of annoyance and delay to trains, by the slipping of the eccentrics on the axle. It was found that the eccentrics and straps got heated, arising, as it was judged, from a deficiency of bearing surface; hence the slipping. The width of the eccentrics was, therefore, increased to 3¾ inches. The trouble has almost entirely ceased, and trains are now rarely delayed by slipping of eccentrics. The eccentrics are fastened by means of set-screws. The weight of the valve-gear is balanced by an adjustable coiled spring attached to a short bell-crank on the lower end of the reversing lever, at the foot-plate.

CHAPTER LXXII.—SIX-COUPLED DOUBLE-BOGIE FAIRLIE LOCOMOTIVE.

DESIGNED BY SIR ALEXANDER M. RENDEL, AND CONSTRUCTED BY MESSRS. NEILSON & CO., GLASGOW, FOR THE MEXICAN RAILWAY.

(Cylinders, outside, 16 inches in diameter, 22-inch stroke; wheels 3 feet 9 inches in diameter; gauge of way 4 feet 8½ inches.)

The Fairlie locomotive, shown in side elevation, fig. 922, is of the maximum-power style of engine. It consists of twin boilers, engines, and bogies, with a central platform for the accommodation of the enginemen. The boilers are united by the fire-boxes and shells at the centre, and are a continuous structure from chimney to chimney.

Each bogie has six wheels, of which the axles are placed 4 feet 1½ inches apart between the centres, making a wheel-base of 8¼ feet for each bogie. The bogies are 22 feet apart between the centres of the pivots, making 30¼ feet of wheel-base. Over the cow-catchers at the ends, the extreme length is 49 feet 8¾ inches.

The barrel of each boiler is of 7/16-inch plates, 3 feet 10¾ inches in diameter outside, enlarged to 4 feet 6 1/16 inches for the ring of plates next the firebox-shell. The joint shell for the two fire-boxes is of 7/16-inch plates, 9 feet long, and 4 feet 1⅜ inches wide, outside. Each fire-box is 4 feet 1⅝ inches long, 3½ feet wide. There are 144 flue-tubes in each boiler, 1⅞ inches in diameter outside, 11 feet 7 13/16 inches long between the plates. The total length of the twin boiler is 31 feet 8 inches between the smoke-box tube-plates. The flue-tubes are inclined downwards towards each smoke-box, to compensate for the water level on inclines: the uppermost row has a fall of 2¾ inches in the length, or at the rate of 1 in 51. The level of water over the fire-box, in the middle, is not materially affected by inclines. The working pressure in the boiler is 165 lbs. per square inch.

Each bogie is constructed of two 1½-inch side frame-plates, 4 feet ¼ inch apart, bound together with transverse plates. The cylinders are 16 inches in diameter, with a stroke of 22 inches. They are fastened on the bogies, outside the side frame-plates, and are connected to the extreme inward pair of wheels, with connecting-rods, 7 feet 11½ inches long, or 8.7 times the length of the crank—an exceptionally great length. The two bogies are connected by a carrier-frame, by which the boiler is effectually supported, also the foot-plates, water-tank, and bunkers; whilst it takes the stress of buffing and traction. The pivot consists of a short gun-metal cylinder, 20 inches in diameter, fixed to the cross-plates of the carrier-frame, which fits into a shallow cast-iron socket fastened to the bogie. To check any tendency to pitching movements, the bogie is steadied at the inner end by a helical spring, which forms an elastic connection between the inner end of the bogie-frame and a transverse plate of the carrier-frame, close to the boiler.

The valve-gear consists of Allan's straight-link motion, for which the reversing shaft is located near the pivot, where the erratic movements are a minimum. Between the boiler and the cylinders steam is necessarily conveyed through ball-and-socket jointed pipes. The bottom of the smoke-box is of cast iron, formed with junction-processes for both the steam and the exhaust pipes. The steam-pipe, of copper, 3¾ inches in diameter, is flange-jointed to a knee-pipe cast on the bottom of the smoke-box. This knee-pipe is connected by a 3¾-inch wrought-iron pipe to a knuckle-chamber, fixed to the bogie-frame, whence the steam passes for-

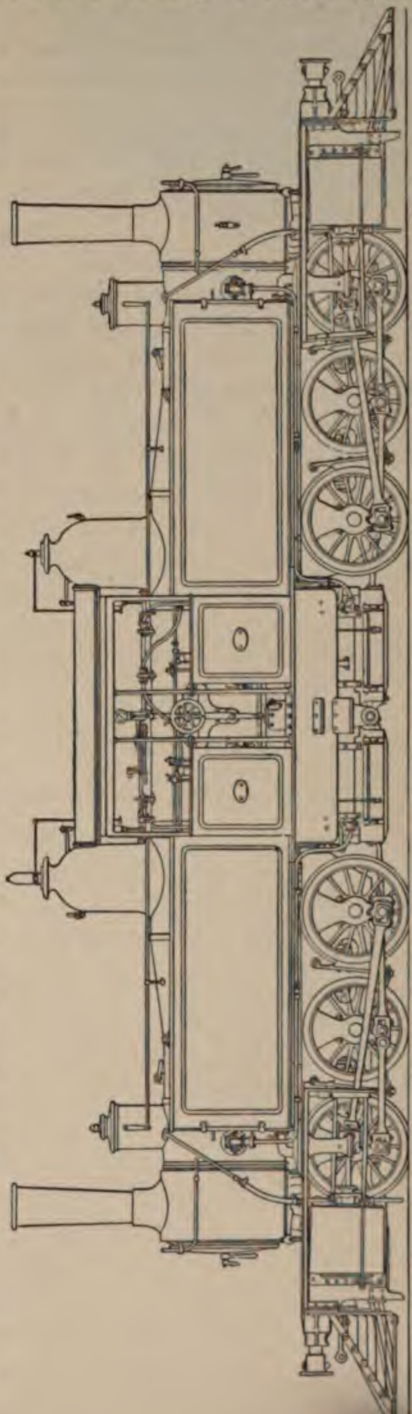


Fig. 922.—The Fairlie Locomotive, for the Mexican Railway. Scale 1/80th, or 3/20ths of an inch to 1 foot.

ward by branch pipes to the two cylinders. The connecting pipe is made with a ball-and-socket joint at each end. The exhaust-steam from the cylinders is conveyed to the blast-pipe in the smoke-box through a 5-inch wrought-iron pipe, with ball-and-socket joints.

	Square feet.
Area of fire-grate, combined	29.4
Heating surface:—Fire-box, combined	166.0
Flue-tubes, do.	1647.0
Total surface	1813.0

or 61.6 times the grate-area.

The engine is said to be capable of drawing a train-weight of 3600 tons, on a level, or 240 carriages weighing 15 tons each. The engine when fully charged carries 2850 gallons of water, and 300 cubic feet of room for coal; and weighs 92¼ tons. The weight, empty, is 67 tons 12 cwts. On regular duty, the engines run on a section of road which, for a length of 14 miles, has many gradients of 1 in 25, with curves of 330 feet radius.

COMPOUND LOCOMOTIVES.

About the year 1852 the continuous-expansion system of Messrs. Samuel & Nicholson was applied to two locomotives on the (then) Eastern Counties Railway, in which two cylinders of unequal diameter were employed. Steam was exhausted at half-stroke from the first cylinder into the second or larger cylinder. At the end of the stroke of the first cylinder the steam was exhausted from it direct into the atmosphere. In this combination the essential principle of compounding was wanting, an independent exhaust taking place from each cylinder.[1]

In 1872 Mr. W. Dawes patented an invention of compound cylinders of locomotives, in which four cylinders were employed, or two compound engines of two cylinders each. According to one system, the four cylinders are ranged across the front of the engine—the two larger between the side frame-plates connected to a cranked axle; the two smaller outside, connected to pins in the driving wheels. On another system the cylinders are all inside, in two tandem systems, the larger cylinders being in front. On a third system inside compound cylinders are applied independently to two separate pairs of driving wheels, which are independent of each other, coupling-rods being dispensed with.

CHAPTER LXXIII.—COMPOUND LOCOMOTIVES.

DESIGNED BY M. ANATOLE MALLET.

M. Anatole Mallet had early prepared designs for compound locomotives, in which one of the cylinders was made larger than the other; and in the beginning of 1876 an order was given to the Creusot Works by the Bayonne and Biarritz Railway Company for three compound locomotives according to M. Mallet's designs.[2] They were four-coupled six-wheel tank-engines, with two outside cylinders, 9.45 inches and 15.75 inches in diameter, with a common stroke of 17.72 inches; having areas in the ratio of 1 to 2.78. The arrangement is shown in fig. 923. The driving wheels were 3 feet 11¼ inches in diameter, and the carrying wheels 2 feet 11½ inches. The wheel-base was 8 feet 10 inches long; the length over all was 18 feet 10 inches. The weight of the engine empty was 15½ tons; in working order, 19½ tons; adhesion weight, 15¼ tons. The working pressure in the boiler was 150 lbs. per square inch. The "starting slide-valve" was fixed on the smoke-box, by means of which the

[1] ccount of this system in the *Proceedings of the Institution of Mechanical Engineers*, 1852;

[2] a paper by M. Anatole Mallet, "On the Compounding of Locomotive Engines," *of the Institution of Mechanical Engineers*, June, 1879; page 328.

steam from the first cylinder might, at starting, be exhausted direct into the atmosphere, whilst steam from the boiler was admitted direct into the second cylinder, sufficiently wire-drawn to avoid an excessive difference of power between the two cylinders. When the valve was shifted into the opposite position the steam from the first cylinder was exhausted to the second cylinder. The engines were first tried in July, 1876; they made steam in abundance, and worked with perfect steadiness. The railway is

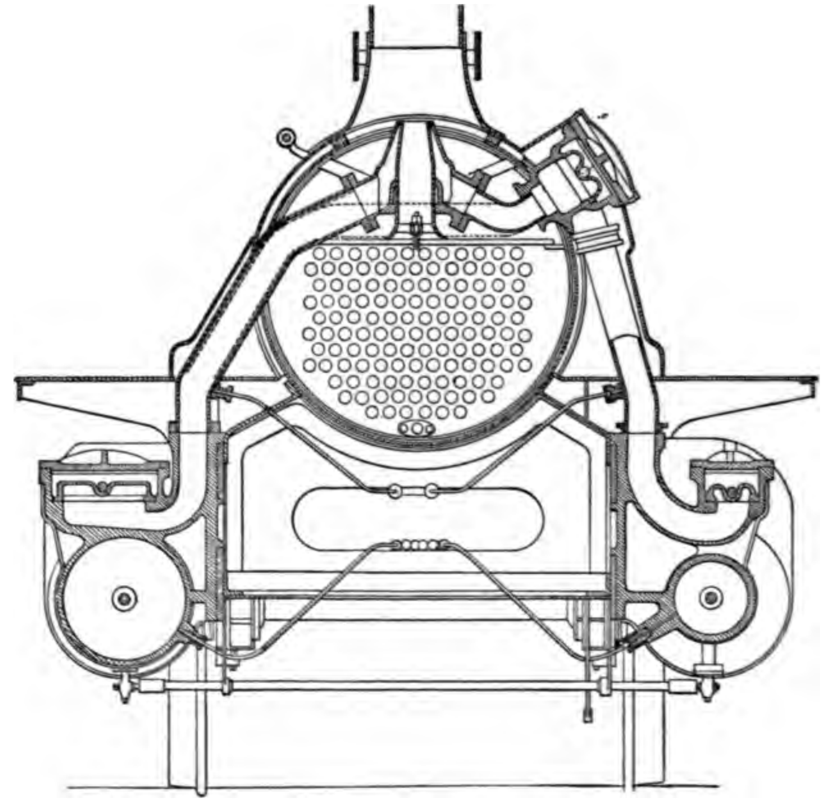


Fig. 923.—Mallet's Compound Locomotive: Section of Smoke-box and Cylinders. Scale 1/24th.

5 miles long, on the 4-feet-8½-inch gauge, with inclines of 1 in 66 and 1 in 70. The trains consisted of four carriages in summer, two in winter; two-storied, 8½ tons each, empty, carrying each about a hundred passengers. The average speed, including stoppages, was 20 miles per hour, and the consumption of Cardiff coal was at the average rate of 13.55 pounds per mile; the lowest consumption was 10.90 pounds per mile.

In the indicator diagrams, taken from one of the engines at a speed of 15.2 miles per hour, or 108 turns per minute, indicating 97.8 horse-power, the steam is shown cut off in both cylinders at 60 per cent of the stroke, the two link-motions being worked together by one reversing handle. A considerable drop in the pressure occurs between the two cylinders; so that the indicator power of the second cylir horse-power, working

compound, is notably less than that of the first cylinder, 60.3 horse-power. The drop is owing to the excessive length of the period of admission to the second cylinder relatively to the ratio of the cylinders, the capacity of the first cylinder being only ($100 \div 2.78 =$) 36 per cent of that of the second. In order that there should not have been any drop, the steam should have been cut off at 36 per cent, when the powers of the two cylinders would have been nearly equal. In the compound engines constructed for the Haironville Railway, provision was made for linking the valve-gears of the two cylinders independently. But it does not appear that this independent action has been retained.

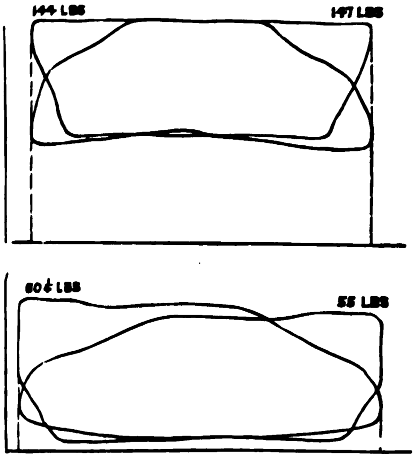
Mr. A. Borodine, chief engineer of the South-Western Railway of Russia, made comparative trials of a compound passenger locomotive on the Mallet system and an ordinary locomotive, both of the series A, constructed for the Kiew-Balta line:—four-coupled engines, having wheels of 5 feet 7 inches in diameter, with 16½-inch cylinders, of 23.6 inches stroke. The slide-valves had 1 inch of lap. The grate-area was 15.05 square feet; the heating surface, 1236 square feet. The engine weighed 29 tons empty, 34 tons full. The working pressure was 120 lbs. absolute per square inch. The engine A 7 was compounded by substituting for one of the cylinders a cylinder of 23.6 inches in diameter, of which the area was twice that of the original cylinder. The two cylinders were completely steam-jacketed, steam being used direct from the boiler. The second cylinder was usually worked with from 70 to 73 per cent admission, and the work of the engine was regulated by varying the admission in the first cylinder, or by the regulator. Steam from the boiler was admitted into both cylinders in starting from stations.

A preliminary test of one of the ordinary engines, A 24—identical with A 7, except in the cylinders—against A 7, was conducted in May, 1881, on the Kiew-Kazatine section, 97½ miles long. The results of twelve double-trips show an economy of steam, of from 4 per cent to 8 per cent; and of fuel, of from 15 per cent to 18 per cent.

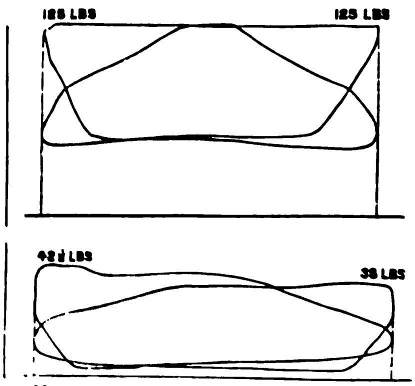
In July, 1881, the two engines took two goods trains exactly alike, one to each, one after the other, at speeds considerably lower than those of the passenger trains; showing an economy of 30 per cent in the consumption of steam by the compound engine, and of 20 per cent of fuel.

The two engines were also tested against each other in the workshops at Kiew. They were, one after the other, lifted off the rails, uncoupled, and worked as portable engines to drive the machinery of the workshop. The speed was 100 turns per minute, equivalent to 20 miles per hour on the rails; and as the power required was much less than the ordinary power of the engines, the ordinary engine, A 21, worked with one cylinder only; and steam was cut off very early in the first cylinder of the compound engine. Besides, the pressure in the boiler was lowered. The work developed indicated from 65 to 74 horse-power for A 21, and from 75 to 93 horse-power for A 7.

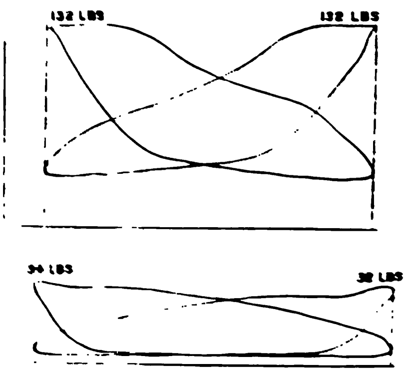
July, 1881.—In working A 21, steam was cut off at 20 per cent,



No. 1.—Cut-off, 70 per cent and 76 per cent; 41 turns per minute.



No. 2.—Cut-off, 55½ per cent and 65 per cent; 48 turns per minute.



No. 3.—Cut-off at 30 per cent and 70 per cent; 44 turns per minute.

Fig. 224.—Mallet's Compound Locomotive, South-Western Railway, Russia. Indicator Diagrams.

having an absolute maximum pressure in the cylinder of 90 lbs. per square inch; and 30 pounds of water was consumed per indicator horse-power per hour.

September, 1881.—In A 21, steam was cut off at 30 per cent, with an absolute maximum pressure of 79 lbs. per square inch in the cylinder; when 28.4 pounds of water was consumed per indicator horse-power per hour.

November, 1881.—In A 7—steam-jacket not working—steam was cut off at 30 per cent in the first cylinder, and at 60 per cent in the second cylinder, with 105 lbs. absolute pressure per square inch in the boiler. The consumption of water was 25 pounds per indicator horse-power per hour.

November (same day), 1881.—The trial of A 7 was repeated, and 25½ pounds of water was consumed per horse-power per hour.

Detailed comparative trials of A 7 and A 22 were conducted on the Kiew-Kazatine line, in which the indicator horse-power was determined. A 22, in September, 1881, consumed 29.95 pounds of water, and 9½ pounds of wood as fuel, per horse-power per hour. A 7, in March, 1882, made two trips, with steam in the jacket, consuming a mean of 28.83 pounds of water, and 7.98 pounds of wood, per horse-power per hour. Without steam in the jacket, in the same month, the means of two trials showed that 25.70 pounds of water, and 7.24 pounds of wood were consumed per horse-power per hour.

From these results it appears that the compound engine, without steam in the jackets, economized 14 per cent of the consumption of water by the ordinary engine, and 24 per cent of

the fuel.[1] It is remarkable that apparently the consumptions were greater when steam was in the jackets than when they were empty—a result most probably due to imperfect conditions.[2]

Subsequently, in 1882, the ordinary engine, A 22, was fitted with steam-jackets, from which the condensation-water escaped through a steam-trap. The total clearances in the cylinder and passages were, for the front end, 7.3 per cent; for the back end, 8 per cent. The engine was tried in the workshops at Kiew, with steam in the jackets, and without it. The average consumptions of water per indicator horse-power per hour, were as follows:—

	Pressure in Boiler.	Without Jackets.	With Jackets.
Cutting off at 30 per cent.........	69 lbs.	33.01 lbs.	28.63 lbs.
Do. 20 „	91 „	32.07 „	26.89 „

The economy effected by the use of steam in the jackets is thus shown to be 13½ per cent, when steam is cut off at 30 per cent; and 16 per cent when steam is cut off at 20 per cent.

In a paper communicated by Mr. Borodine to the Institution of Mechanical Engineers, in 1886,[3] on the subject of the experiments just noticed, in addition to other comparative experiments, he draws results from the comparative trials of A 7 and A 22, made without steam in the jackets, which are here thrown into tabular form:—The economy of fuel is affected by the evaporative efficiency, which for A 22 was 3.33 pounds of water per pound of fuel; and for A 7, 3.82 pounds.

Without Steam in the Jackets.

Number of Expansions.	Water per I.H.P.			Economy of Fuel (Wood) by Compounding.
	A 7 Compound.	A 22 Ordinary.	Economy of Water by Compounding.	
ratio.	pounds.	pounds.	per cent.	per cent.
4.8	21.78	27.94	22	32
4.5	22.04	27.99	21	31
3.3	23.10	26.62	13	23
2.5	26.18	28.43	9	20

Extending his comparisons, Mr. Borodine finds that for equal consumptions of 5236 pounds, or 80.4 cubic feet of water per hour, the ordinary engine, A 22, developed 187 horse-power; and the compound engine, A 7, developed 222 horse-power, or 19 per cent more.

The sample indicator diagrams, figs. 924, were taken from a six-coupled-

[1] The greater economy of fuel than of water here announced has its parallel in the economy effected by the employment of feed-water heaters in locomotives. See a paper by D. K. Clark, "On the Improvement of Railway Locomotive Stock, and the Reduction of the Working Expenses," in the *Proceedings of the Institution of Civil Engineers*, vol. xvi. (1856–57), page 3.

[2] These particulars of trials in Russia are derived from a communication made by M. Mallet to the *Société des Ingenieurs Civils, Paris*, in 1883.

[3] See "Experiments on the Steam-jacketing and Compounding of Locomotives in Russia," in the *Proceedings of the Institution of Mechanical Engineers* (1886), page 297.

wheel compound locomotive on the South-Western Railway of Russia, having

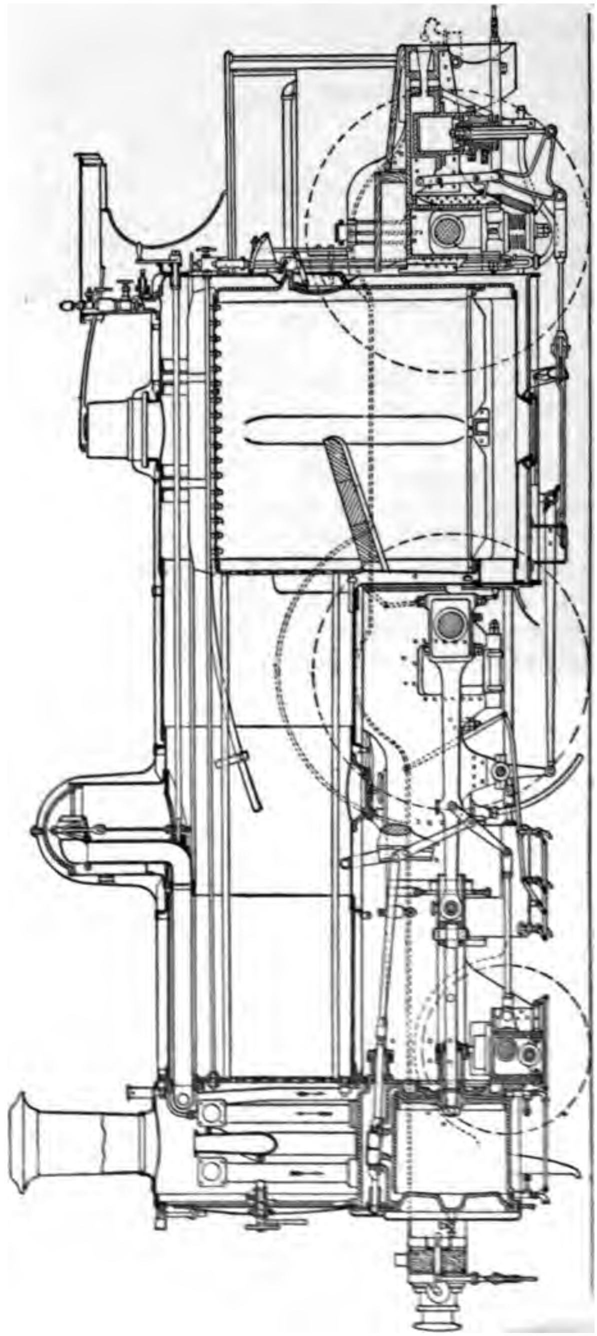


Fig. 925.—Compound Locomotive (Dreadnought type), designed and constructed by F. W. Webb. Longitudinal Section. Scale 1/50th.

cylinders, of the area-ratio 2, 15.18 inches and 21.[illegible] diameter, with a stroke of 24 inches; 52-inch wheels; and weig[illegible] tons.

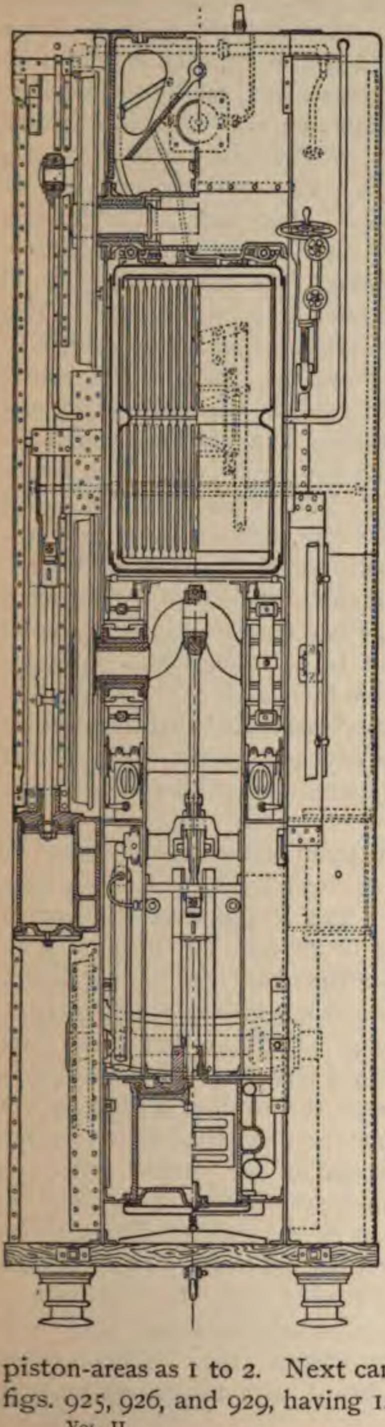


Fig. 926.—Compound Locomotive (Dreadnought type), designed and constructed by F. W. Webb. Sectional Plan. Scale 1/50th.

CHAPTER LXXIV.

THREE-CYLINDER COMPOUND LOCOMOTIVES.

DESIGNED AND CONSTRUCTED BY MR. F. W. WEBB, FOR THE LONDON AND NORTH-WESTERN RAILWAY.

(Cylinders 14 inches and 30 inches in diameter, stroke 24 inches; driving wheels 6¼ feet; gauge of way 4 feet 8½ inches.)

Mr. F. W. Webb, in 1878, converted one of the old engines on the London and North-Western Railway into a compound engine, on Mallet's system, and worked it for five years on the Ashby and Nuneaton line. In 1881–82 he constructed at Crewe a compound engine, the Experiment, of a new type, which he had patented. He employed three steam cylinders: two first or high-pressure cylinders, outside, connected to the trailing axle; and one second or low-pressure cylinder, inside, connected to the driving or middle axle. Thus two pairs of wheels were driven independently, without coupling-rods. The exhaust-pipes from the first cylinders were laid round the smoke-box, inside, and thus the steam, exposed to the heat, was dried more or less before entering the second cylinder. The first cylinders were 11½ inches in diameter, and the second cylinder was 26 inches, with strokes of 24 inches; the driven wheels were 6½ feet in diameter, and Joy's system of valve-gear was employed. The ratio of the combined areas of the first cylinders to the area of the second cylinder, was as 1 to 2.55. Encouraged by the performance of the Experiment, Mr. Webb constructed other compound engines of the same type, but with 13-inch first cylinders instead of 11½-inch cylinders: making the ratio of piston-areas as 1 to 2. Next came the Dreadnought class, of the same type, figs. 925, 926, and 929, having 14-inch and 30-inch cylinders, with a ratio of

piston-areas as 1 to 2.30, with strokes of 24 inches. The steam-ports of the first cylinders are $^1/_{11.2}$ part of the area of the pistons; those of the second cylinder are $^1/_{19.6}$ part of the piston-area. The driven wheels are 6¼ feet in diameter, 9 feet 8 inches apart between centres; the leading wheels, 3 feet 9 inches in diameter, are fitted with radial axle-boxes, fig. 927, making up the total wheel-base 18 feet 1 inch. The working pressure of steam is 175 lbs. per square inch. The driving and trailing axle journals are 7 inches in diameter, 13½ inches long. The central crank-pin is 7¾ inches in diameter, 5½ inches long. The central connecting-rod, figs. 928, is of steel, 6¼ feet long, or 6¼ times the length of the crank. The smaller end is solid, bushed with phosphor-bronze, ¼ inch thick. The bush is secured by the stem of the oil-cup. The cup is secured by a split pin. The larger end is forked to receive the brasses, which are held in place by a block let into the fork, fastened by a through-bolt with double-nuts at each end. The brasses are adjusted by means of a wedge to a taper of 1 in 16, fastened by pins to a through-bolt, fixed by double-nuts at each end. The valve-gear is so constructed that the motions for the first and second cylinders can be regulated independently of each other.

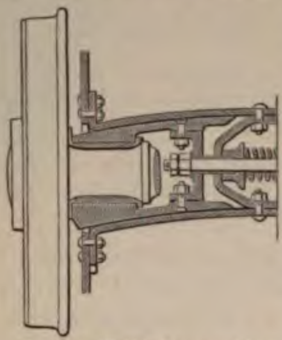
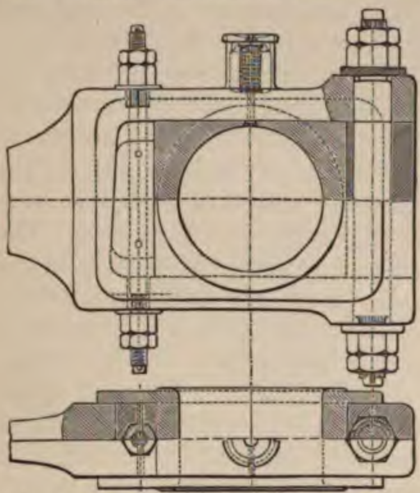


Fig. 927.—Webb's Compound Locomotive: Radial Axle-boxes of Leading Wheels. Scale 1/24th.



Figs. 928.—Webb's Compound Locomotive: End of Central Connecting-rod. Scale 1/10th.

The main side frame-plates are of steel, ⅞ inch thick, and are 4 feet apart. The length over the buffer-beams is 27 feet 1¼ inches. The barrel of the boiler is of ½-inch plates, and is 4 feet 3 inches in diameter, 11 feet long. There are 225 brass flue-tubes, 11¼ feet long. The area of fire-grate is 20.5 square feet. The heating surface of the fire-box is 159.1 square feet, and that of the flue-tubes is 1242.4 square feet; together, 1401.5 square feet, or 68.4 times the grate-area. The weight of the engine, empty, is 39½ tons; full, 42½ tons, distributed thus:—12½ tons on the leading wheels, 15 tons on the middle wheels, 15 tons on the trailing wheels. The tender weighs 12 tons 1 cwt. empty, and is constructed to carry 1800 gallons, or 288 cubic feet, or 8 tons of water, and 5 tons of coal. Loaded thus, it weighs 25 tons gross; and the engine and tender together weigh 67½ tons.

According to Mr. Webb's most recent design (the Teutonic type, 1889), the Dreadnought type has been followed, with the exception that

the driving wheels are 7 feet 1 inch in diameter instead of 6¼ feet; and

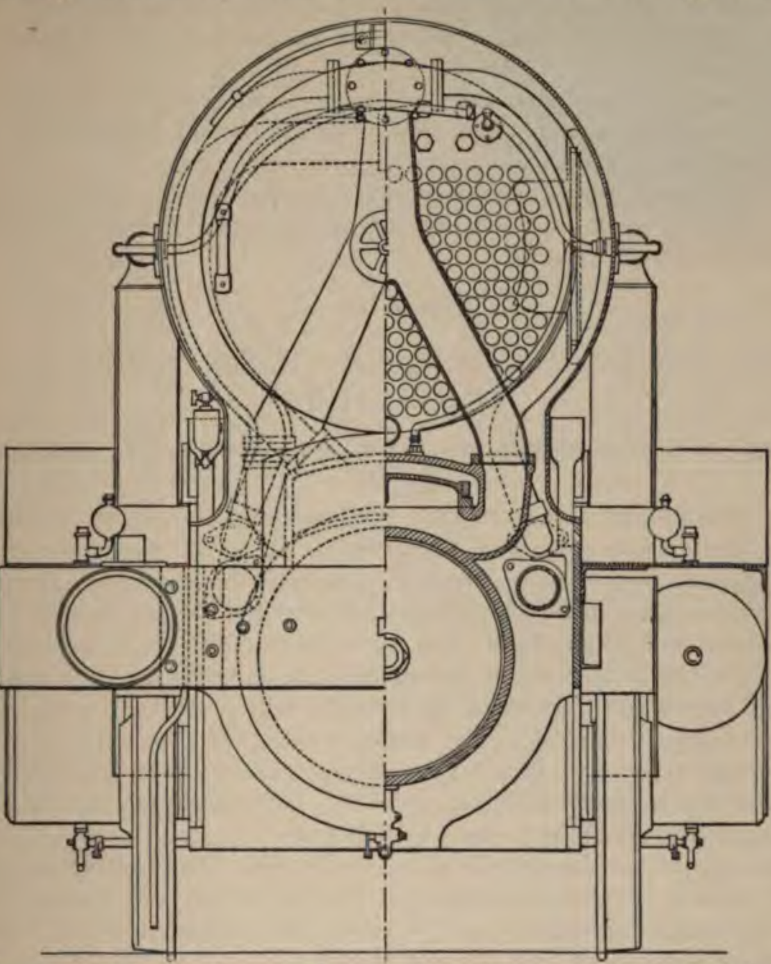


Fig. 929.—Webb's Compound Locomotive: Sectional End View, showing Second Cylinder. Scale 1/24th.

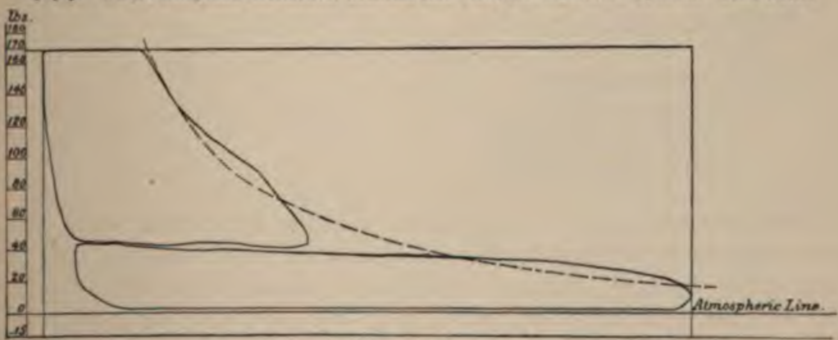


Fig. 930.—Indicator Diagrams from the Compound Locomotive Teutonic, on Mr. Webb's System; London and North-Western Railway.

an improvement in the Joy valve-gear for securing a better cut-off, shown

in the combined indicator diagrams, fig. 930, for which the pressure in the boiler was 173 lbs. per square inch, whilst the pressure in the first cylinder during admission was about 170 lbs. per square inch, and in the second cylinder 40 lbs.

For the first cylinders, the slide-valves have a lap of 7/8 inch, lead 1/8 inch, maximum travel 3¾ inches. For the second cylinder the lap is 1 inch, lead ½ inch, maximum travel 5½ inches.

Seventy-seven compound locomotives on Mr. Webb's system are now (May, 1890) at work. They completed a mileage run of over 14,000,000 miles by March 31, 1890.

Chapter LXXV.—OUTSIDE-CYLINDER COMPOUND LOCOMOTIVES.

DESIGNED BY MR. VON BORRIES, FOR THE PRUSSIAN STATE RAILWAY, HANOVERIAN SECTION.

Mr. Von Borries has, since 1881, been working compound locomotives on the Hanoverian section of the Prussian State Railway. He made a new departure in designing six-wheel compound locomotives. He places the cylinders, two in number, outside, behind the leading wheels, with a communication between them; and works them direct to the trailing axle, behind the fire-box, to which the middle axle is coupled. The cylinders are 16½ inches and 23⅝ inches in diameter, with a stroke of 22⅞ inches; in the ratio of 1 to 2.05. The driven wheels are 6 feet 1¼ inches in diameter, at 7 feet 10½ inches apart between centres; the leading wheels are 3 feet 8½ inches in diameter, 9 feet 2¼ inches from the middle wheels between centres; making a wheel-base of 17 feet ¾ inch.

The area of the fire-grate is 18.73 square feet. The heating surface of the fire-box is 78½ square feet; of the flue-tubes, 969.3 square feet; together, 1047.8 square feet, or 56 times the grate-area. The working pressure of steam is 171 lbs. per square inch.

	Tons.	Cwts.	Qrs.
Weight of engine, empty	33	19	2
Do. do. full	37	8	0
Distribution of weight:—			
Leading wheels	11	16	0
Middle wheels (driven)	12	16	0
Trailing wheels (driven)	12	16	0

A special starting-valve is placed in the receiver, by which, when closed, communication between the cylinders is cut off. For starting, the valve is shut, either by hand or automatically; then steam is turned on from the boiler into the first cylinder, and also to d cylinder through a small pipe from the main steam-pipe. from the first cylinder fills the receiver, and when s equal to that of the steam admitted to the lve opens

automatically, the direct steam is shut off from the second cylinder, and regular communication is opened between the two cylinders.

The Walschaerts gear is employed for reversing, and is so planned that nearly equal powers are developed in the two cylinders. The lifting wypers are placed on the reversing shaft at different angles, in such a manner that in forward gear the shifting of the block in the second expansion-link is not so great as in the first expansion-link. The travel of the second valve, and the period of admission correspondingly, are therefore greater than those for the first valve. The corresponding admissions are as follows:—

First cylinder—75 per cent.	Second cylinder—75 per cent.
40 "	50 "
20 "	33 "

Compared with ordinary engines of like dimensions, working on the same lines, and taking the same trains, the compound locomotives effect an economy of from 14.3 per cent to 21 per cent in fuel.[1]

Chapter LXXVI.—INSIDE-CYLINDER AND WOOLF COMPOUNDED LOCOMOTIVES.

DESIGNED AND CONSTRUCTED BY MR. CHARLES SANDIFORD, FOR THE SCINDE, PUNJAUB, AND DELHI RAILWAY.

Mr. Charles Sandiford, of Lahore, compounded two of the inside-cylinder locomotives of the Scinde, Punjaub, and Delhi Railway, the Vampire and the Vulcan, and sent them for trial in June, 1884. In the Vampire, the two original 15-inch cylinders were replaced by an 18-inch and a 24-inch cylinder—as large as could conveniently be provided for, with the original stroke, 22 inches. The slide-valve of the second cylinder was on a vertical face, and was worked direct; that of the first cylinder, on a horizontal face, was worked through a rocking shaft: both with the Stephenson link-motion. To assist in starting, when the first cylinder was on a dead centre, steam could be admitted direct to the second cylinder. With this contrivance, it is said, there has not been any difficulty in starting. The engine has been regularly employed on goods and mixed trains, at speeds of from 18 to 22 miles per hour, taking with ease a gross weight, including the engine itself, of 500 tons. For an average actual gross weight of 489 tons, at an average speed of 20 miles per hour, 33.10 pounds of Bengal coal has been consumed per train-mile; against 38.28 pounds per train-mile by the ordinary coupled engines with 16-inch cylinders, of 24 inches stroke—showing a difference in favour of the compound engine of 5.18 pounds of coal per mile, or an economy of 13½ per cent.

The other engine, the Vulcan, was compounded by replacing the two

[1] The materials for this notice of Mr. Von Borrie's compound locomotive are derived from *Engineering*, April 30, 1886; page 434.

original 16-inch cylinders by two 17-inch inside cylinders, and adding two separately-connected 11¾-inch cylinders outside, with the original stroke of 24 inches. The crank of each first cylinder is diametrically opposed to that of the corresponding second cylinder, forming a Woolf combination. The Stephenson link-motion was retained for working the valves, and it answered very well: the inside cylinders having vertical valves worked direct, and the outside cylinder having horizontal valves with rocking shafts. The consumption of Bengal coal averaged, in 1885, 33.13 pounds per train-mile, for an average gross weight of 520 tons, at 20 miles per hour average speed; making an economy of nearly 13½ per cent on the consumption of the ordinary engines in the same district. The working pressure is 120 lbs. per square inch. The two-cylinder compound engine is liked better by the drivers than the four-cylinder engine. But the four-cylinder engine has a sharper blast by a good deal, and is capable of steaming better than the two-cylinder engine, although the latter is never short of steam.[1] Here is a case in which, as it happens, the economy effected on the Woolf system is equal to that effected on the intermediate-receiver system. But the results are not without qualification comparable.

Chapter LXXVII.—Inside-Cylinder Compound Locomotives.

DESIGNED AND CONSTRUCTED BY MR. T. W. WORSDELL, FOR THE NORTH-EASTERN RAILWAY.

(Cylinders 18 inches and 26 inches in diameter, stroke 24 inches; wheels 7 feet 1¼ inches; gauge of way 4 feet 8½ inches.)

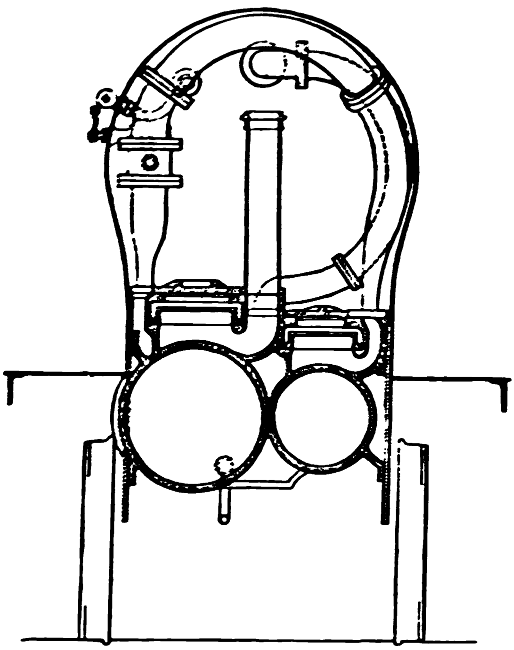
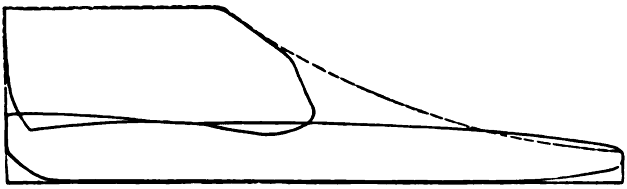


Fig. 931.—Compound Locomotive, by Mr. T. W. Worsdell, for the Great Eastern Railway. Scale 1/36th.

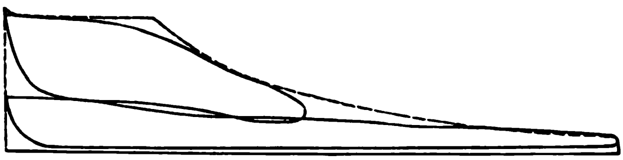
Mr. T. W. Worsdell, in 1885, designed and constructed his first compound passenger locomotive for the Great Eastern Railway, in which two cylinders were employed, placed side by side, between the side frame-plates, as shown in fig. 931, 18 inches and 26 inches in diameter, with a stroke of 24 inches: working to the crank-axle in the usual manner, with 7 feet driving and trailing wheels coupled, and a bogie in front. The

[1] See a paper "On the Working of Compound Locomotives in India," in the *Proceedings of the Institution of Mechanical Engineers*, 1866; page 355.

capacity-ratio of the cylinders was 1 to 2.09. The engine was fitted with



No. 1.



No. 2.

No. 3.

Figs. 932.—Worsdell's Compound Locomotive: Indicator Diagrams Combined. Vertical scale, 160 lbs. per inch.

Joy's valve-gear, and steam could be turned on direct to the second cylinder, when required, for starting.

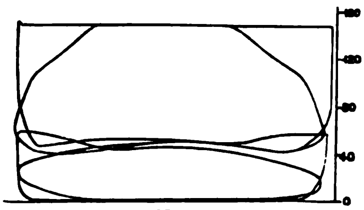
The total wheel-base was 20 feet 1½ inches long.

The area of the fire-grate was 17.3 square feet, and the heating surface was 1200 square feet, or 69.4 times the area of the fire-grate. The weight of the engine, empty and full, was distributed as follows:

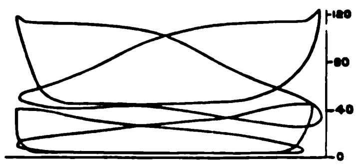
	Weight Empty.			Weight Full.		
	tons.	cwts.	qrs.	tons.	cwts.	qrs.
At bogie wheels......	13	7	0	14	15	2
„ driving wheels....	14	3	2	4	16	21
„ trailing wheels....	13	12	1	14	18	0
	41	2	3	44	10	0

The tender has capacity for 3200 gallons of water, and 5 tons of coal.

Sample indicator diagrams are shown in figs. 933; and they are combined in figs. 932, whereon also the so-called "theoretical" expansion-curves are traced. The table No. 182 gives particulars of the diagrams and the performance:—



No. 1.



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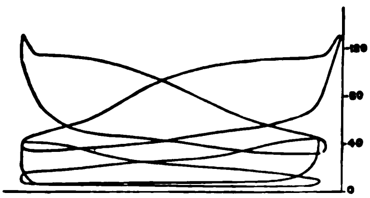


No. 3.

Figs. 933.—Worsdell's Compound Locomotive: Indicator Diagrams.

Table No. 182.—Worsdell's Compound Locomotive, Great Eastern Railway:—Performance, May 7, 1885.

Cylinders 18 inches and 26 inches; 24-inch stroke.

No. of Indicator Diagrams	1.	2.	3.
Where taken	Kentish Town	Stanstead	Whittlesford
Train-load, carriages	6	13	13
Speed, in miles per hour	15	42	63
Steam cut off at, per cent of stroke	75	50	40
Maximum pressure per square inch above the atmosphere	148 lbs.	114 lbs.	117 lbs.
Effective mean pressure, 1st cylinder	92 "	47.77 "	41.6 "
Do. do. 2d do.	43.7 "	22.46 "	21.9 "
Indicator horse-power, 1st cylinder	170.2 H.P.	247.10 H.P.	323.26 H.P.
Do. do. 2d do.	168.72 "	242.14 "	353.24 "
Do. do. total	338.92 "	489.24 "	676.50 "

The contributions of power from the two cylinders are nearly equal, proving an excellent distribution. But, in the third case, there is about 10 per cent greater power from the second cylinder than from the first.

More recent results of performance on the Great Eastern Railway, show the comparative consumption of coal on like duty, by eleven Worsdell compounded locomotives, fitted with Joy's gear, and seven ordinary locomotives, of No. 562 class. For three months ending May 21, 1886, the respective performances were as follows:—

	Compound.	Ordinary.
Train-miles run	109,469½	64,671
Engine-miles run	112,754¾	66,656¼
Coal consumed	28,767 cwts.	19,547 cwts.
Do. per train-mile	29.4 lbs.	33.8 lbs.
Do. per engine-mile	28.5 "	32.8 "

There is a clear difference of 4.4 pounds per train-mile run in favour of the compounded locomotives, or a reduction of 13 per cent on the ordinary consumption.

When Mr. Worsdell turned out his first compound engine, it was at once found impossible to start the engine by simply admitting steam from the boiler direct into the second valve-chest, in the case of the first crank resting on a dead centre. For, whilst steam was acting on the second piston, it was also exerting back pressure on the first piston, through the connecting-exhaust-pipe between the cylinders. It was necessary, therefore, to prevent the steam from passing to the exhaust side of the first piston. Hence the need for an intercepting valve in the intermediate pipe. For this purpose, Mr. Von Borries employs a disc-valve, working on a horizontal spindle; but Mr. Worsdell prefers a hinged flap-valve. By the simple combination of a starting valve and an intercepting valve, all difficulty in starting is removed.

Mr. Worsdell's more recent design (1889) of compound locomotives, constructed for the North-Eastern Railway, to work the high-speed express trains between Newcastle, Berwick, and Edinburgh, is that of a single-driving wheel engine, with a leading bogie, figs. 934, 935, and 936.

It is compounded on the Worsdell and Von Borries system. The cylinders are inside, 18 inches and 26 inches in diameter, with a stroke of 2 feet; having the capacity-ratio of 1 to 2.09. The valve-chests are on the tops of the cylinders. The steam-ports are, for the first cylinder, 11¾ inches by 1¾ inches, making an area of 20½ inches, or $^1/_{12.4}$ part of the area of the piston. For the second cylinder they are 17 inches by 2 inches, having an area of 34 square inches, or $^1/_{15.6}$ part of the piston-area. The lap of the slide-valves, of which the first is of the Trick pattern, is 1⅛ inches, the lead $^3/_{16}$ inch, and the maximum travel 5¼ inches. Inside clearance is provided: ¼ inch for the first cylinder, ⅛ inch for the second cylinder. The piston-rods are of steel, 3 inches in diameter; the slide-blocks are 15 inches long; the connecting-rods are of iron, 6 feet 1 inch long, or 6.17 times the length of the cranks. The wheels, axles, frames, and boiler-shell are of steel. The driving wheels are 7 feet 1¼ inches in diameter; the bogie wheels, 3 feet 7¼ inches; and the trailing wheels, 4 feet 7¼ inches. The wheel-tyres are 5½ inches wide, 3 inches thick at the tread. The crank-axle is 7¾ inches in diameter at the middle, with two journals 8 inches in diameter, 9 inches long. The trailing axle is 6¾ inches in diameter, with journals 7 inches by 11 inches; the bogie axles are 5¾ inches in diameter, with journals 6 inches by 9 inches. The longitudinal frame-plates are 1 inch thick; the bogie side-plates are ¾ inch thick. The bogie axles are 6½ feet apart; and the total wheel-base is 21 feet 11 inches.

The barrel of the boiler is of ½-inch plates, 4¼ feet in diameter, 10 feet 7 inches long. The firebox-shell is of $^9/_{16}$-inch plates, except the front plate, ⅝ inch. It is 6 feet long, 3 feet 11 inches wide. The fire-box is of copper. There are 203 flue-tubes, 1¾ inches in diameter outside, 10 feet 11⅛ inches long between plates, pitched at 2½ inches between centres. The grate-area is 17.23 square feet; the heating surface is 1136.12 square feet, or 66 times the grate-area.

The working pressure in the boiler is 175 lbs. per square inch.

	Empty.			Full.		
Weight of engine:—	tons.	cwts.	qrs.	tons.	cwts.	qrs.
At bogie wheels,........................	13	14	0	14	12	0
„ driving wheels,........................	16	6	2	18	0	0
„ trailing wheels,........................	9	10	2	10	5	2
Total weight of engine,................	39	11	0	42	17	2
Tender,........................	17	16	1	38	0	0
	57	7	1	80	17	2

The combined starting and intercepting valves are shown in figs. 937.

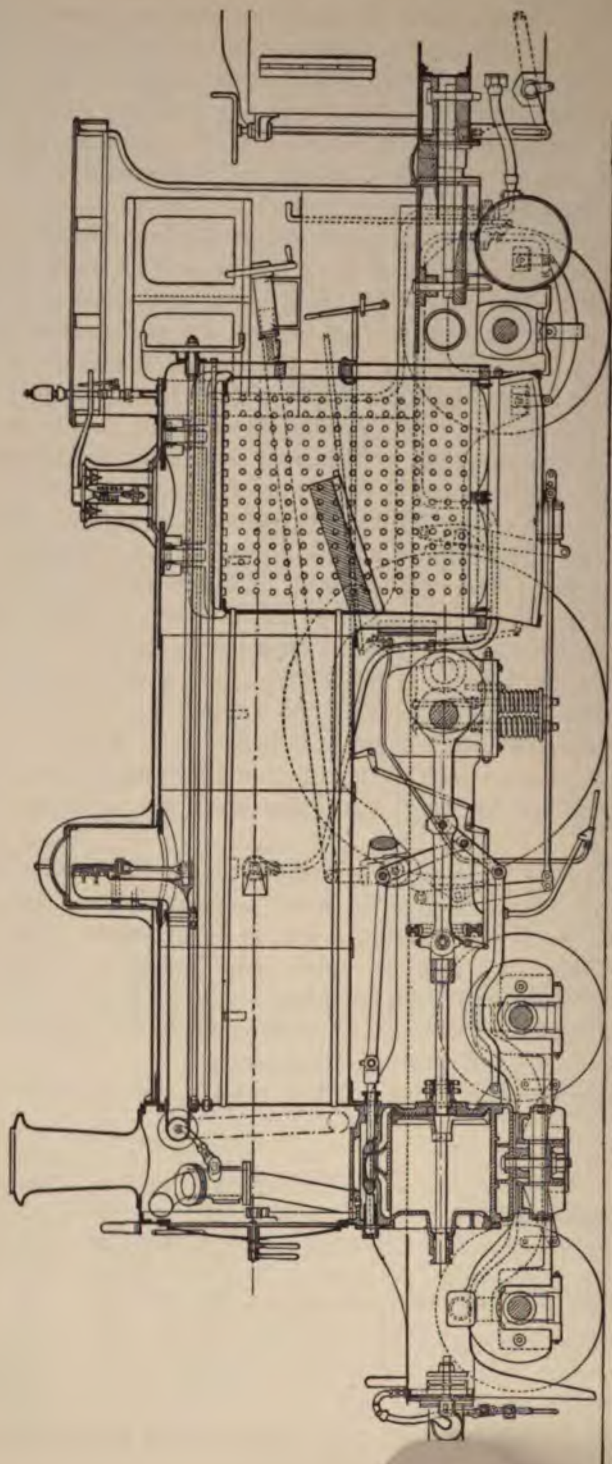


Fig. 934.—Compound Locomotive, Worsdell and Von Borries System. Longitudinal Section. Scale 1/50th.

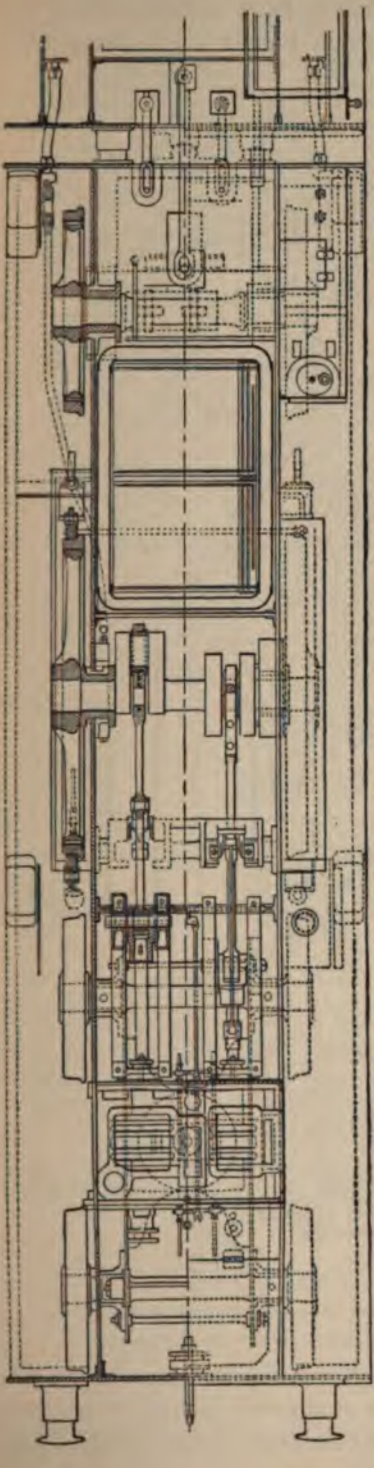


Fig. 935.—Compound Locomotive, Worsdell and Von Borries System. Sectional Plan. Scale 1/50th.

Steam from the boiler is conducted through a 5-inch copper pipe to the valve-chest of the first cylinder, and is exhausted through an 8-inch iron pipe, arched to follow the contour of the smoke-box, into the second valve-chest. In this arched pipe the intercepting valve is located, over the second cylinder —a flap-valve hinged to one side of a special valve-chamber forming part of the exhaust conduit. The flap-valve, in its normal position, hangs vertically, as shown in dot-lining, figs. 937, No. 1, clear of the thoroughfare. The starting valve is fixed on the outside of the smoke-box. It consists of two cylindrical valves—one within the other, on the same axis, as shown in figs. 937, Nos. 2 and 3. The inner and smaller valve is fastened on the starting rod, and, when the rod is pulled out by the starting handle, the smaller valve is pulled off its seat with in the larger valve, and gives passage to steam in small quantity, which is admitted through a small hole in the larger valve. By a further movement of the starting handle the larger valve is pulled off its seat, and there is free passage for steam from the boiler to the second valve-chest. A piston facing the valves is at the same time driven outward by the pressure of the steam; and, by the rod of the piston, engaged with an arm on the hinge-pin of the intercepting valve, which is prolonged through the side of the smoke-box, the intercepting valve is closed simultaneously with the admission of the steam from the boiler to the second valve-chest. The valves are each under the pressure of a helical spring, as shown in No. 3, by which they are kept closed when not pulled outwards by the medium of the starting handle. The blast-pipe nozzles are 4¾ inches in diameter, in both the compound and the non-compound engines.

The engine is fitted with Joy's valve-gear. By a differential adjustment of the quadrants in which the expansion blocks work, the periods

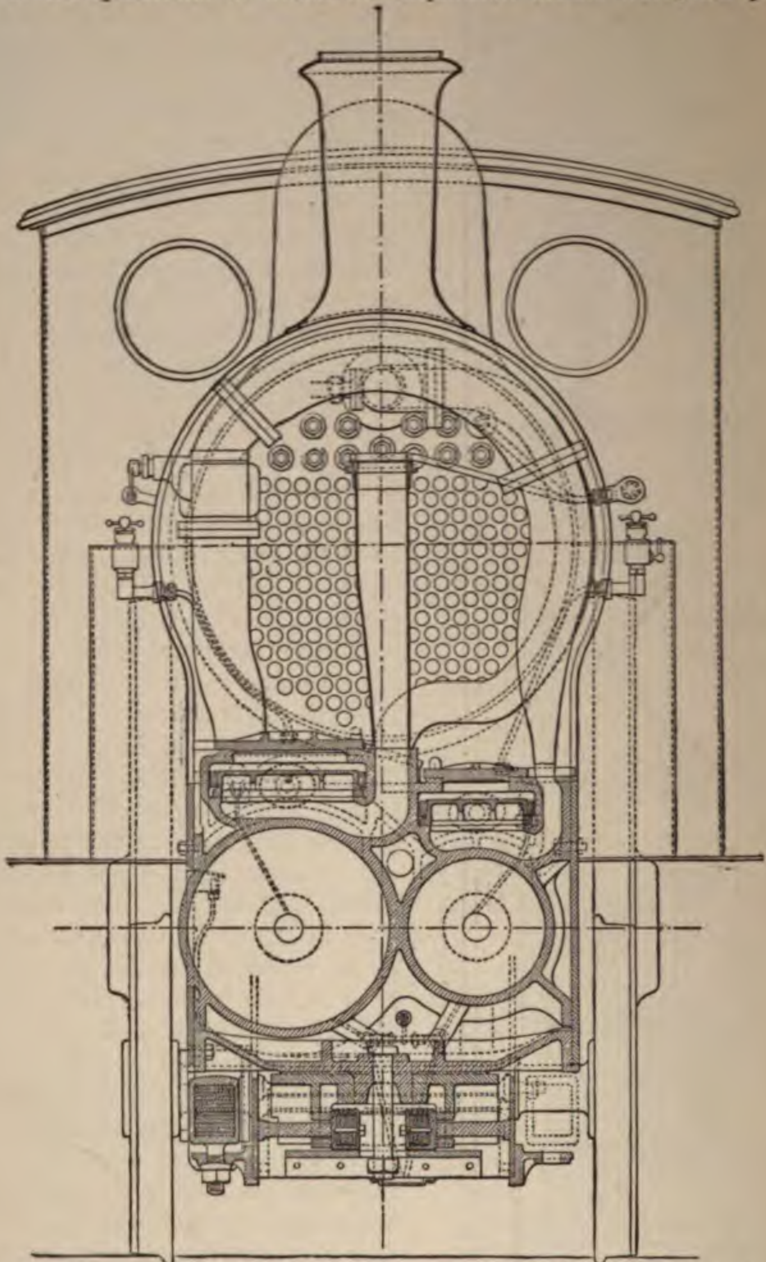
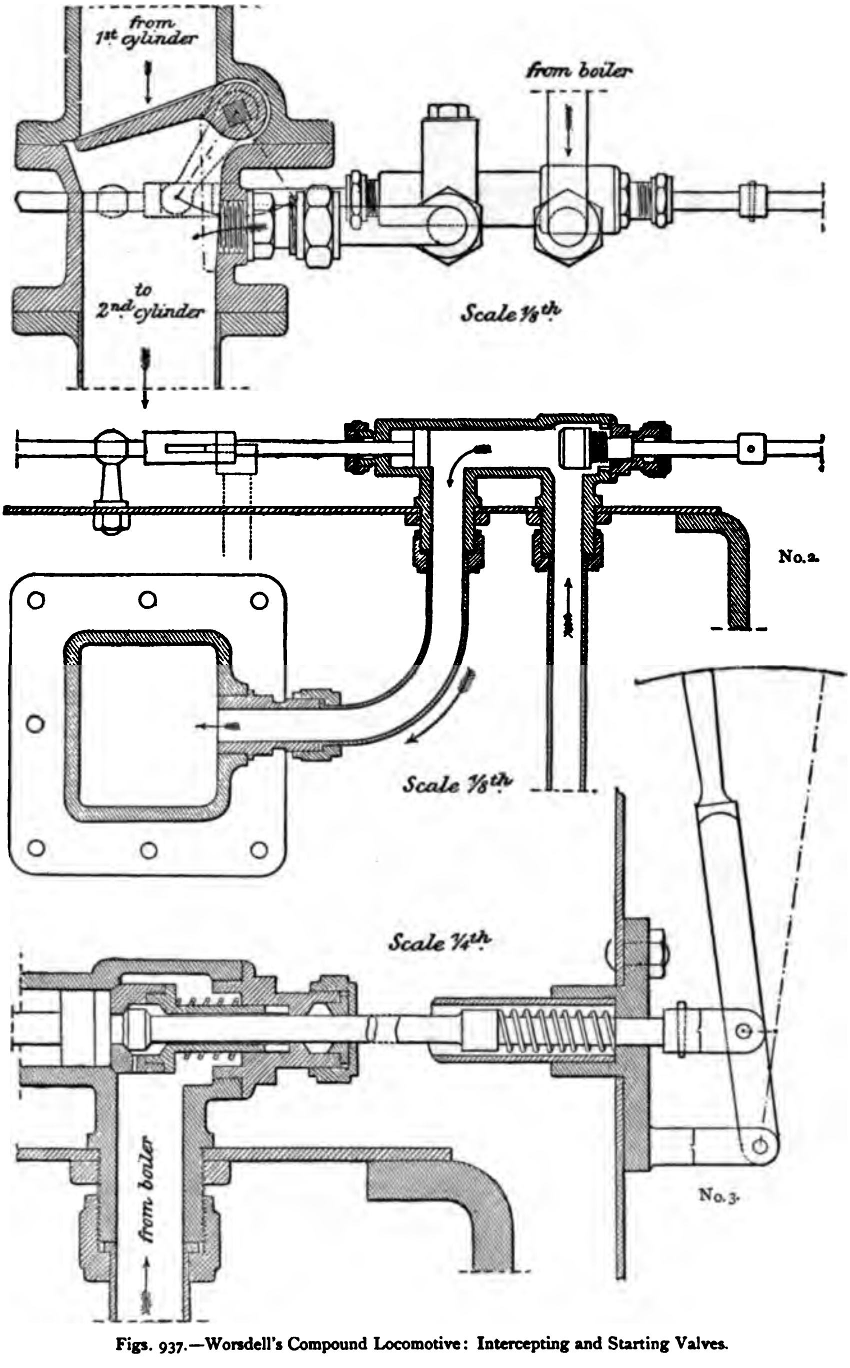


Fig. 936.—Worsdell's Compound Locomotive: Section of Smoke-box and Cylinders. Scale 1/24th.

of admission may be so controlled as to equalize the works done in the two cylinders. Indicator diagrams taken from a compound passenger locomotive on the North-Eastern Railway are shown combined in figs. 938 and 939.

It appears that the initial pressure in the second cylinder was higher than



Figs. 937.—Worsdell's Compound Locomotive: Intercepting and Starting Valves.

the terminal pressure in the first cylinder. Cutting-off in fig. 938 at 70 per

cent, and in fig. 939 at 50 per cent, the nominal ratios of combined expansion were respectively about 1 to 3, and 1 to 4.

The usual formation of the Scotch express trains worked by engines of the class now under notice, ranges from 10 to 12 vehicles—never fewer than 10—averaging 14 tons weight. Returning, they bring back the return mail from Edinburgh, frequently consisting of 16 carriages. During holiday traffic one engine alone took an excursion train of 24 carriages filled, weighing about 11 tons each, from Newcastle to Carlisle and back.

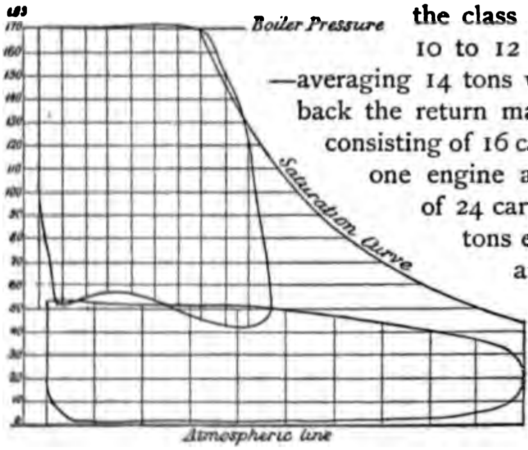


Fig. 938.—North-Eastern Railway: Passenger Express Compound Locomotive. Indicator Diagrams.

In January and February, 1888, comparative trials of compound and ordinary passenger locomotives were made between Heaton Junction and Tweedmouth, on the North-Eastern Railway, with the following results:—

	Compound. No. 18.	Ordinary. No. 902.
20 vehicles,	160 tons.	160 tons.
Engine and tender,	81.35 „	71.70 „
Engine, tender, and train,	241.35 „	231.70 „
Miles run: Engine,	960 miles.	952 miles.
Miles run: Train,	892½ „	892½ „
Coal consumed per train-mile,	28.3 lbs.	36.0 lbs.
Saving by compound engine,	7.7 „	—
	21½ per cent.	—
Water per pound of coal,	7.68 lbs.	7.78 lbs.
Total time running,	27 hr. 38 min.	27 hr. 36 min.

In the year 1886–87, the comparative consumption of coal by compound and ordinary goods engines working the Newcastle, York, and Leeds heavy express was as follows:—

	Compound.	Ordinary.
Number of engines on the duty,	10	10
Total miles run	185,001	156,500
Total coal consumed	[illegible] cwts.	68,228 cwts.
Do. do. per mile	[illegible] lbs.	[illegible] lbs.
Saving by compound engines	[illegible]	—
	[illegible] per cent.	—

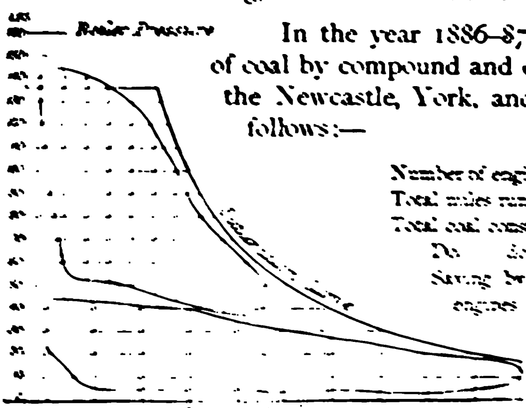


Fig. [illegible].—North-Eastern Railway: Passenger Express Compound Locomotive. Indicator Diagrams.

According to Mr. Worsdell's latest designs (1890), fig. 940, whilst the cylinders are inside the longitudinal frame-plates, the valve-chests are outside. In order to make room for the cylinder they are placed at different levels,

and of course their axes are not parallel. The slide-valves are driven by Joy's gear, by the medium of rocking shafts. With a bogie in front, there is but one pair of driving wheels; and to ensure a sufficiency of adhesion, Gresham's sand blast is employed. The webs or limbs of the cranks are circular discs, 4 inches thick.

The cylinders are 20 inches and 28 inches in diameter, with a stroke of 24 inches, having the capacity-ratio of 1 to 1.96. The driving wheels are 7 feet 7½ inches in diameter. The total wheel-base is 21 feet 11 inches.

There are 203 flue-tubes 1¾ inches in diameter externally. The grate-area is 20.7 square feet; the heating surface is 1139 square feet, or 55 times the grate-area.

The working pressure in the boiler is 175 lbs. per square inch.

The weight of the engine in working order is:—

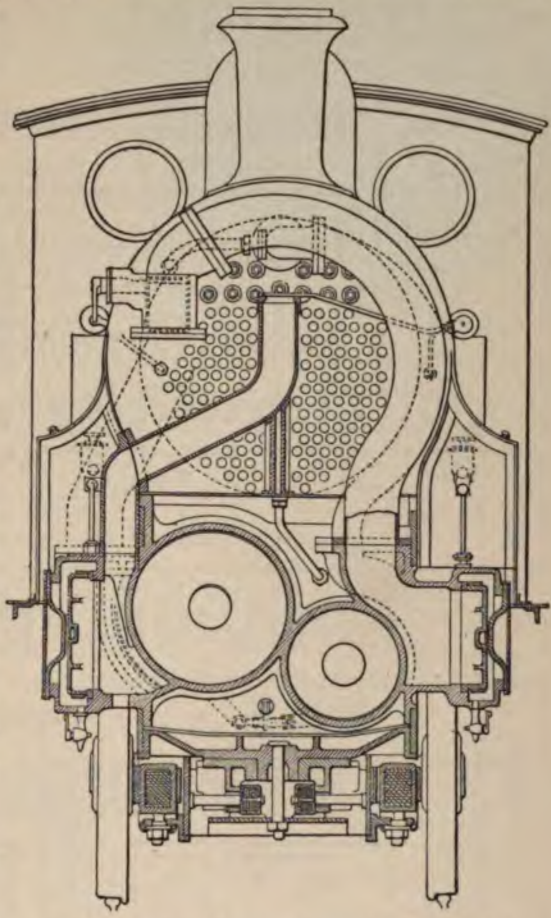


Fig. 940.—Worsdell's Compound Locomotive: Latest Design. Scale 1/32d.

	Tons.	Cwts.	Qrs.
At the bogie,	15	18	2
„ driving wheels,	17	15	0
„ trailing wheels,	13	0	0
Total weight in working order,	46	13	2
Do. empty,	44	3	0

It is stated that an engine of this class on one occasion attained a speed of 86 miles per hour.

A list of compound locomotives, on the Worsdell and Von Borries system, either at work, in course of construction, or ordered, in November, 1888, comprising 86 engines on the North-Eastern Railway, is given in the table No. 183.[1]

[1] Derived from Mr. Herbert Lapage's paper on "Compound Locomotives," in the *Proceedings of the Institution of Mechanical Engineers, 1880;* page 104.

Table No. 183. Compound Locomotives on the Worsdell and Von Borries System, at Work, in Construction, or Ordered. November, 1888.

The dimensions given relate to some only of the engines.

Railway	Class and Number of Engines		Number of Wheels Coupled	Driving Wheels Diameter		Cylinders			Boiler Pressure per Sq. In. above Atmosphere	Weight in Working Order
						Diameters		Stroke		
	Class	No.	No.	feet	inches	inches	inches	inches	lbs.	tons
North Eastern	Goods	72	Six	5	1⅜	18	26	24	160	40.35
	Pass.	14	Four	6	8¼	18	26	24	175	42.45
Great Eastern	Goods	1	Six	4	10	18	26	24	150	39.40
	Pass.	11	Four	7	0	18	26	24	160	44.50
London and South Western	Pass.	1	Four	7	1	18	26	24	160	45.80
Bengal and Nagpur	Mixed	4	Six	4	4	18	26	26	161	46.70
Prussian State	Goods	70	Six	4	4⅜	18⅛	25⅝	24¾	176	37.75
	Pass.	59	Four	6	1¼	17⅜	24¾	24¾	176	38.35
Alsace and Lorraine	Pass.	1	Four	4	11	14½	21⅝	19¾	176	34.50
Western of Buenos Ayres	Pass.	2	Four	5	11	16½	24	24	175	38.75
Central of Entre Rios	Goods	1	Six	3	9	16	23	24	175	37.00
Buenos Ayres and Rosario	Pass.	7	Four	5	7½	16	23¼	24	160	37.14
North Western Argentine	Mixed	6	Six	4	0	16	23	22	170	32.50
Argentine Central Northern	Goods	27	Eight	3	6	16	23	24	175	33.00
	Pass.	11	Four	4	6	15	21½	22	175	29.50
Saxony	Goods	15	Six	4	6¾	18	25½	24	176	40.80
	Pass.	10	Four	6	1¾	17¼	24¾	21⅝	176	42.30
Wurtemburg	Pass.	5	Four	5	5	16½	23⅝	22	176	36.40
Nizam State	Mixed	2	Six	4	3	18	26	26	161	44.85
Santa Fé and Cordoba Great Southern	Goods	6	Six	4	6	17½	25	25	170	46.75
	Pass.	4	Four	5	6	16	23	24	170	38.50
Central Argentine	Goods	5	Six	4	6	18	26	24	165	43.70
	Pass.	5	Four	5	1½	18	26	24	165	44.00
Italian Meridional	Goods	2	Six	4	5	18	25⅝	25⅝	180	38.00
Argentine Great Western	Mixed	8	Six	4	3	17½	25	24	175	
Moscow and Warsaw	Goods	1	Six							
Anglo Chilian Nitrate	Goods	9	Eight	3	2	17	24	21	170	51.00
Manchester, Bury, Rochdale, and Oldham Tramways	Pass.	1	Four	2	7	9	14	14	180	12.80
Rossendale Tramway	Pass.	1	Four	2	6	9	14	14	180	10.00

There are now (April, 1890) about 600 compound locomotives on the Worsdell and Von Borries system, of which there are 120 on the North-Eastern Railway. The average results of 12 months' working of these 120 engines, compared with the non-compound engines on the railway, drawing the same trains, 150 tons weight, show an economy of 22 per cent of coal.

Mr. Thomas Urquhart, on the Grazi and Tsaritsin Railway, South-east Russia, has ascertained an average economy of 18½ per cent of petroleum refuse in the performance of 12 compound goods engines and three compound passenger engines, as against the non-compound. His trials of petroleum refuse against coal and anthracite for fuel, are noticed in the next chapter. He finds that the second crank should lead, as it gives a better distribution of steam than in engines in which the first crank leads. The capacity of the receiver, between the first and second cylinders, has been successively increased from equality to the volume of the first cylinder, to 1.3 times and 1.8 times, with marked advantage. The pressure in the second cylinder does not drop so fast, with the larger receiver.[1]

OTHER LOCOMOTIVES.

CHAPTER LXXVIII. PETROLEUM-REFUSE AND TAR-BURNING LOCOMOTIVES.

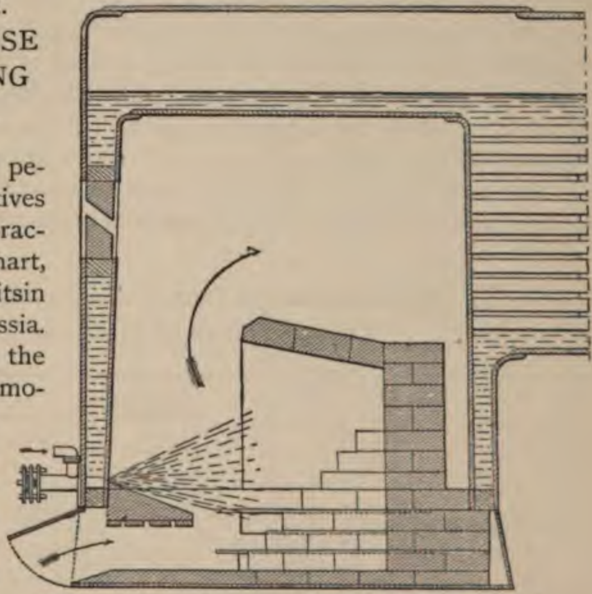


Fig. 941.—Urquhart's Locomotive: Petroleum Fuel—Combustion Chamber. Scale 1/30th.

The combustion of petroleum refuse in locomotives has been successfully practised by Mr. Thos. Urquhart, on the Grazi and Tsaritsin Railway, South-east Russia. Since November, 1884, the whole stock of 143 locomotives under his superintendence has been fired with petroleum refuse. The oil is injected from a nozzle through a tubular opening in the back of the fire-box, by means of a jet of steam, with an induced current of air; illustrated by fig. 941, as applied to six-wheeled

[1] See Mr. Urquhart's paper "On the Compounding of Locomotives burning Petroleum Refuse in Russia," in the *Proceedings of the Institution of Mechanical Engineers*, 1890.

passenger and goods engines. A brickwork cavity—or "regenerative or accumulative combustion-chamber"—is formed in the fire-box, into which the combined current breaks as spray against the rugged brickwork-slope. In this arrangement, the brickwork is maintained at a white heat, and

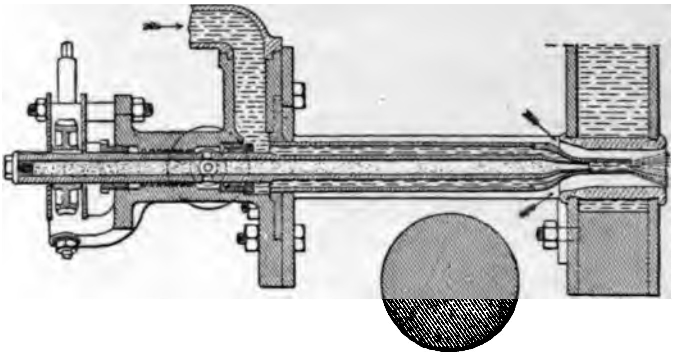


Fig. 942.—Urquhart's Locomotive: Petroleum Fuel—Spray Injector. Scale 1/8th.

combustion is complete and smokeless. The form, mass, and dimensions of the brickwork are the most important elements in such a combination. The spray injector is shown in fig. 942.

Compressed air was tried instead of steam for injection, but no appreciable reduction in consumption of fuel was noticed.

The evaporative power of petroleum refuse is given as 19,832 heat units, equivalent to the evaporation of 20.53 pounds of water from and at 212° F., or to 17.1 pounds at 8½ atmospheres, or 125 lbs. per square inch, effective pressure: against the highest evaporative duty, 14 pounds of water under 8½ atmospheres per pound of fuel, or nearly 82 per cent efficiency.

The relative performances of goods locomotives, using coal and petroleum refuse as fuel, are given in tables 184 and 185.

Table No. 184.—Comparative Performance of Goods Locomotives, using Coal and Petroleum Refuse as Fuel.

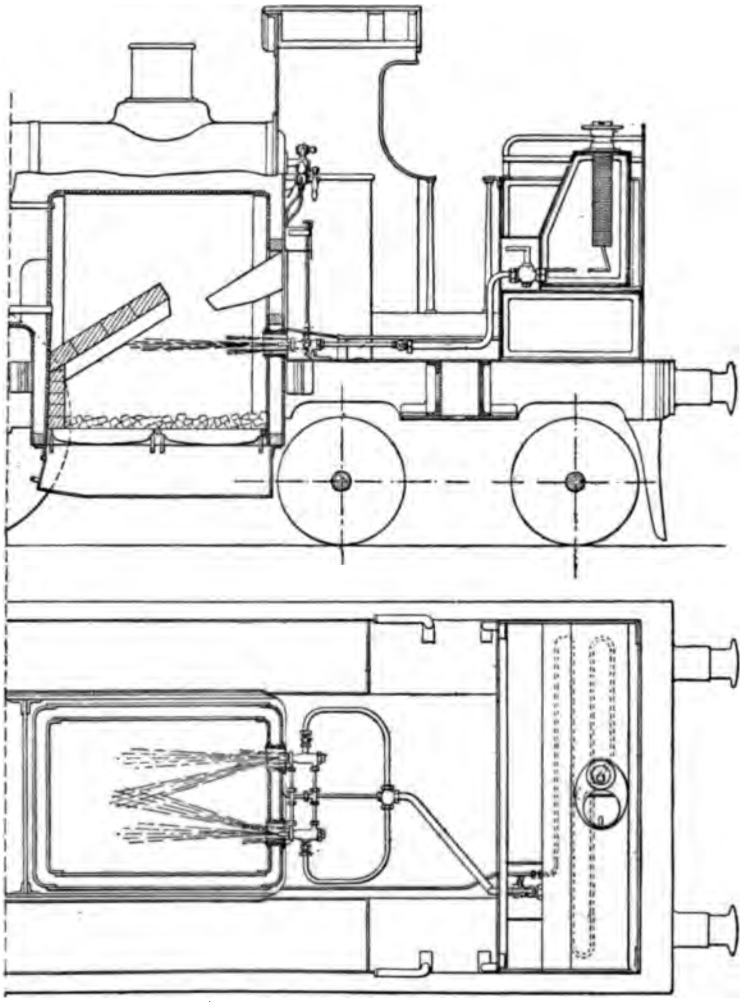
Engine.	Fuel.	Average Number of Wagons.[1]	Total Train-miles.	Total Engine-miles.	Consumption of Fuel per Engine-mile.	Cost.
					lbs.	pence.
6-wheel coupled 36-ton goods	Coal in 1882......	26.32	866,584	1,341,782	55.65	7.64
	Petroleum refuse in 1887........	23.54	1,024,778	1,450,948	30.72	4.43
8-wheel coupled 48-ton goods	Coal in 1882......	37.52	433,780	518,313	79.08	11.02
	Petroleum refuse in 1887........	39.32	754,870	971,421	40.47	5.84

[1] Each wagon 16 tons gross weight.

Table No. 185.—COMPARATIVE PERFORMANCE OF GOODS LOCOMOTIVES, USING ANTHRACITE AND PETROLEUM REFUSE AS FUEL.

Engine.	Fuel.	Weight of Train.	Train-miles.	Consumption of Fuel per Train-mile.
		tons.		lbs.
6-wheel coupled	Anthracite, July, 1883	480	194	65.92
	Petroleum refuse, July, 1883	480	194	31.46
8-wheel coupled	Anthracite, May, 1884	620	410	79.38
	Petroleum refuse, May and June, 1884	706	1,639	40.25

On the Great Eastern Railway, Mr. James Holden introduced, in 1887



Figs. 943.—Holden's Apparatus for Burning Liquid Fuel in Locomotives. Scale 1/48th.

a system of burning liquid fuel in locomotives. Four locomotives are

now (April, 1890) at work on that railway, fitted on this system, namely:—

	Cylinders.	Wheels.
1. 4-coupled-wheel passenger express......18	ins. × 24 ins.	7 feet 0 ins.
2. Single do. do. 18	„ × 24 „	7 „ 6 „
3. 4-coupled passenger tank..................17	„ × 24 „	5 „ 4 „
4. 6-coupled shunting..........................16½	„ × 22 „	4 „ 0 „

In these engines a mixture of creosote oil and gas tar is used as fuel; but in future it is likely to be replaced by foreign petroleum refuse.

On Mr. Holden's system, illustrated by figs. 943 and 944, as applied to a tank-locomotive, in addition to the liquid fuel, a very thin fire of coals, about 3 inches in depth, is maintained on the grate, as a basis of combustion: the tar being injected into the fire-box through two tubular openings at the back. The jets strike against and under the ordinary fire-brick arch, and a thin lining wall of fire-brick is erected against the tube-plate, to receive any spray of liquid deflected from the inclined fire-brick arch. The nozzles or burners of the injectors, shown in detail, figs. 945, are constructed with two apertures, so formed that, whilst a mixture of currents is effected, no liquid is directed against the side plates of the fire-box. The liquid fuel is admitted through an annular nozzle, encasing another annular nozzle through which steam is discharged. Air is admitted from the front through the central nozzle or passage, in the inner portion of which it meets and is mixed with the steam and the liquid currents. An additional supply of steam is delivered through a hollow ring surrounding the injector, in separate small jets, which are directed downwards and upwards towards the end of the nozzle, crossing the issuing

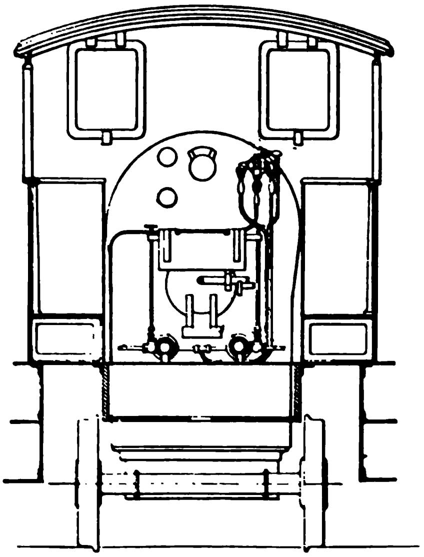


Fig. 944.—Holden's Apparatus for Burning Liquid Fuel in Locomotives. Scale 1 48th.

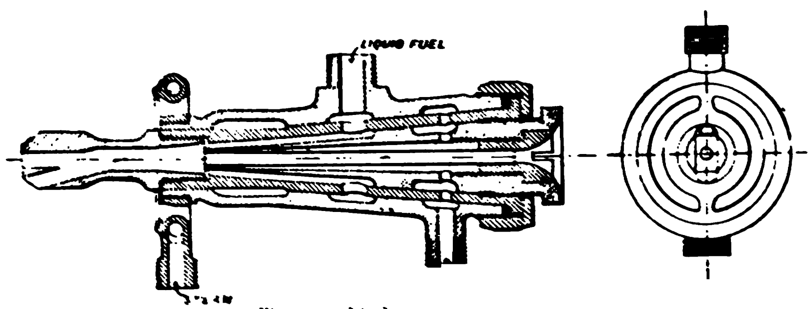


Fig. 945. Liquid

jets of liquid fuel, and conve ... ixed with a

supplementary induced supply of air. By means of this combination, a combustible mixture is formed and is injected into the fire-box, burning with a brilliant smokeless flame. The ashpan damper is maintained a little open, to keep the fire alight; but, in order to prevent the coal burning away too rapidly, the greater part of the air so admitted is excluded from the coal by a stratum of chalk or lime laid on the grate.

The liquid fuel is contained in a tank having a capacity of 210 gallons, at the back of the engine, as shown in figs. 943, from which the liquid falls by gravitation. The comparative results of one week's performance of two tank-locomotives of the same class, Nos. 193 and 194, were as follows:—

	Pounds Consumed per Mile.				Cost per Mile for Fuel.
	Coal.	Liquid Fuel.	Chalk.	Total.	
	lbs.	lbs.	lbs.	lbs.	*d.*
No. 193.........	14.2	11.0	.80	26.0	2.28
No. 194.........	29.1	—	—	29.1	2.33

In making up this statement, coal is charged at 14*s.* 11*d.* per ton, liquid fuel at 1⅛*d.* per gallon of 11 pounds, and chalk at 5*s.* 6*d.* per ton.

CHAPTER LXXIX.—FIRELESS LOCOMOTIVE.

DESIGNED BY MESSRS. LÉON FRANCQ AND MESNARD.

The distinguishing principle of the Francq locomotive is that it depends for the supply of steam on its spontaneous generation from a body of heated water in a reservoir. As steam is generated and drawn off, the pressure falls; but, by providing a sufficiently large volume of water heated to a high temperature, at a pressure correspondingly high, a margin of surplus pressure may be secured, and means may thus be provided for supplying the required quantity of steam for the trip.

The fireless locomotive, figs. 946 and 947, designed for the service of the Metropolitan Railway of Paris, has a cylindrical reservoir, having segmental ends, about 5 feet 7 inches in diameter, 26¼ feet in length, with a capacity of about 620 cubic feet. Four-fifths of the capacity is occupied by water, which is heated by the aid of a powerful jet of steam supplied from stationary boilers. The water is heated up until equilibrium is established between the boilers and the reservoir. The temperature is raised to about 390° F., corresponding to 15 atmospheres total pressure, or 225 lbs. per square inch. The steam from the reservoir is passed through a reducing valve, by which the steam is reduced to the required pressure. It is then passed through a tubular superheater situated within the receiver at the upper part; and thence through the ordinary regulator to the cylinders. The exhaust steam is expanded to a low pressure, in order to obviate noise of escape. In certain cases the exhaust steam is condensed in closed

vessels, which are only in part filled with water. In the upper free space a pipe is placed, into which the steam is exhausted. Within this pipe another pipe is fixed, perforated, from which cold water is projected into the surrounding steam, so as to effect the condensation as completely as

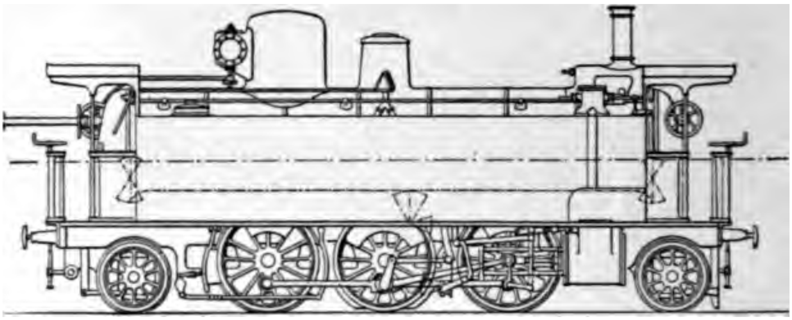


Fig. 946.—Fireless Locomotive, by Francq and Mesnard. Scale 1/100th.

may be. The heated water falls on an inclined plane, and flows off without mixing with the cold water. The condensing water is circulated by means of a centrifugal pump driven by a small three-cylinder engine.

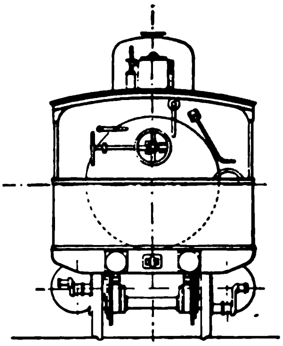


Fig. 947.—Fireless Locomotive. End Elevation. Scale 1/100th.

In working off the steam from a pressure of 15 atmospheres to 4½ atmospheres, 530 cubic feet of water at 390° F. is sufficient for the traction of the trains, for working the circulating pump for the condensers, for the breaks, and for electric lighting of the train. At the stations the locomotive takes from 2200 to 3300 pounds of steam—nearly the same as the weight of steam consumed during the run between two consecutive charging stations. There is 210 cubic feet of condensing water. Taking the initial temperature at 60° F., the temperature rises to about 180° F. after the longest runs underground.

The locomotive has ten wheels, on a base 24 feet long; of which six are coupled, 4½ feet in diameter. The extreme wheels are on radial axles. The cylinders are 23½ inches in diameter, with a stroke of 23½ inches.

The engine weighs, in working order, 53 tons, of which 36 tons are on the coupled wheels. The speed varies from 15 miles to 25 miles per hour. The trains weigh about 140 tons.

Chapter LXXX.—WOOTTEN'S LOCOMOTIVE.

Mr. J. E. Wootten designed and constructed a locomotive boiler for the combustion of anthracite and lignite, though specially for the utilization as fuel of the waste produced in the mining and preparation of anthracite,

amounting to from 20 to 25 per cent of the output of the mines of Pennsylvania. The special feature of the engine is the fire-box, which is made of great length and great breadth, extending clear over the wheels, giving an area of from 64 square feet to 76 square feet. The draught diffused over these large areas is so gentle as not to lift the fine particles of the fuel. The system is available for both passenger traffic and goods traffic; and there are many such engines in use on the Reading and other lines having access to the anthracite region.

A number of express engines having this type of boiler are engaged on the fast trains between Philadelphia and Bound Brook. The firebox-shell is 8 feet 8 inches wide, and 10 feet 5 inches long; the fire-box is 8 feet by 9½ feet, making 76 square feet of grate-area. The grate is composed of bars and water-tubes alternately. The height of the fire-box is only 2 feet 5 inches above the grate. The grate is terminated by a bridge of fire-brick, beyond which a combustion-chamber, 27 inches long, leads to the flue-tubes, 184 in number, 2 inches in diameter. The cylinders are 21 inches in diameter, with a stroke of 22 inches. The driving wheels, four-coupled, are 5 feet 8 inches in diameter. The engine weighs 44 tons, of which 29 tons are driving. The heating surface of the fire-box is 135 square feet, that of the flue-tubes is 982 square feet; together, 1117 square feet, or 14.7 times the grate-area. Hauling 15 passenger cars, weighing with passengers 360 tons, at an average speed of 42 miles per hour, over ruling gradients of 1 in 89, the engine consumes 62 pounds of fuel per mile, or 34¼ pounds per square foot of grate per hour.

Comparing by trial a freight-engine of the Wootten type with an ordinary Consolidation engine, the following average results were obtained in running trips of 110½ miles:—

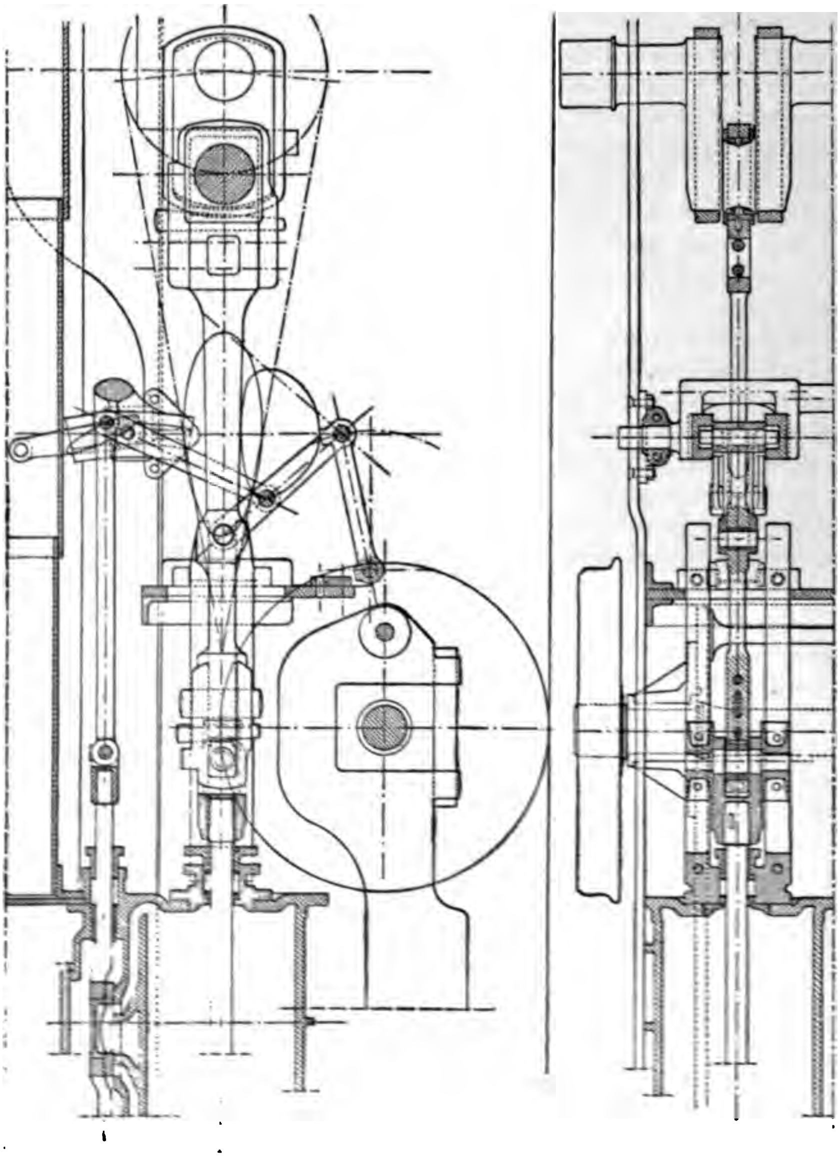
	Ordinary.	Wootten.
Coal consumed per mile run..................	97½ lbs.	73 lbs.
Water evaporated per pound of fuel.........	6.61 „	8.93 „

In virtue of the mildness of the draught in the Wootten engine, there is an exemption from the emission of sparks and cinders.

On the Eastern Railway of France, the Wootten engine evaporates 30 per cent more water than the ordinary goods engines of that railway. In Upper Italy, 8.26 lbs. of water was evaporated per pound of American anthracite; 4.20 pounds per pound of Monte-Murlo lignite; 5.29 pounds per pound of San Giovanni lignite; 6.26 pounds per pound of Valdairo lignite; 8.66 pounds per pound of Cludinico lignite. With Cardiff coal, 8.9 pounds was evaporated per pound. The Italian engineers concluded that in the Wootten locomotive the inferior fuels of the Italian mines could be consumed with an evaporative efficiency more than double that obtained in the ordinary locomotives.

CHAPTER LXXXI.—JOY VALVE-GEAR.

The Joy valve-gear, in its normal form, as adapted for locomotives, is shown in figs. 948. It has already been noticed at page 33, where the



Figs. 948.—Joy Valve-gear, arranged for Locomotives, as applied on the Midland Railway. Scale 1/24th.

leading features of the gear have been mentioned. It may be added that the angular position of the sector is determined by means of the reversing lever, by which it is maintained stationary; and that the reciprocating travel of the valve is effected as the result of the reciprocating vertical

movement of the sliding-block in the slot of the sector, by which, according to the degree of obliquity to which it is set, the horizontal element of the motion, and the corresponding travel of the valve, are determined. Ascending, the block is moved horizontally towards the front of the engine. In descending, it is moved backwards. As already explained, the pin of the slide-block coincides in position with the central pivot of the quadrant, at the two dead-points of the crank; and thus it follows that the valve is in the same position for the commencement of each stroke, whatever may be the angle of the quadrant and the corresponding travel of the valve; and that therefore the lead of the valve is constant for all periods of admission.

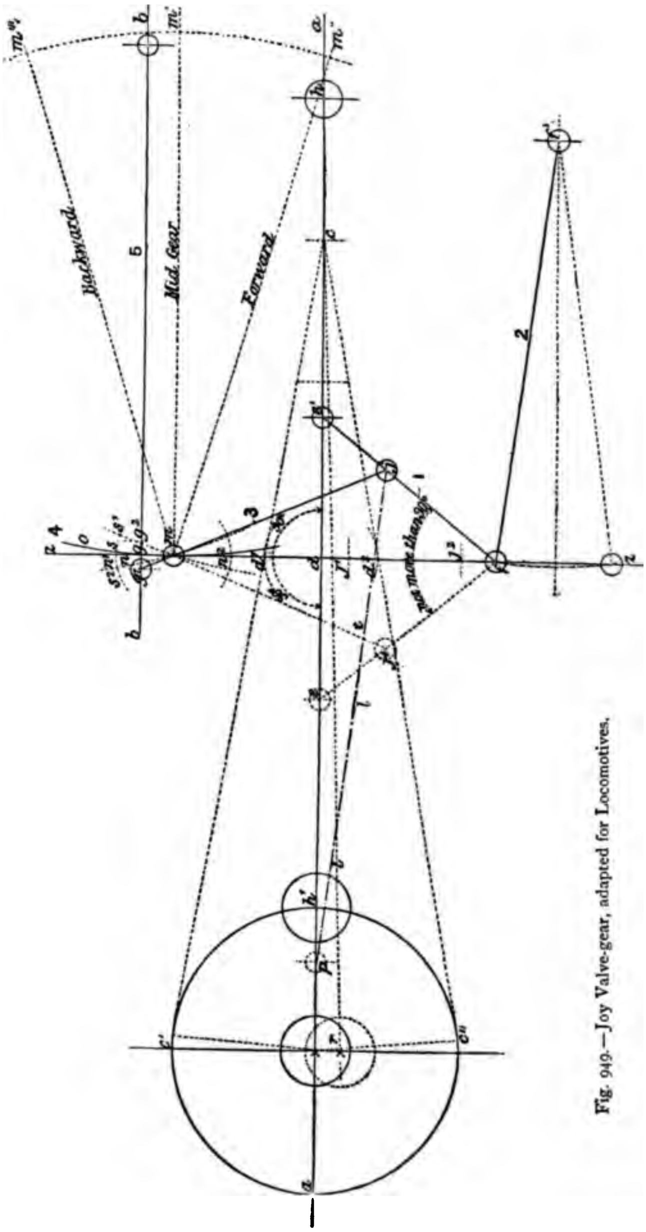


Fig. 949.—Joy Valve-gear, adapted for Locomotives.

Mr. Joy gives the following "Rules for laying down the centre-lines" of his valve-gear:—

"Lay down the centre-line of the cylinder *a a*, fig. 949, and that of the valve-spindle *b b*, at the relative distances required for the engine to which the application is to be made, the valve-spindle centre-line being, however, in the plane of the vibration of the connecting-rod. Draw the path of the crank-pin, and the centre-lines of the connecting-rod *c c′ c c″* for both

upper and lower positions when the piston is at half-stroke. Take a point d on the centre-line of the connecting-rod, where its vibration between d^1 and d^2 is equal to about double the length of the full stroke of the valve (it is better to allow rather more than less). It may, however, be chosen very much to suit the other arrangements of the engine, such as the position of the slide-bar brackets, &c., getting, however, if possible, a vibration of the connecting-rod fully equal to double the stroke of the valve, to avoid too great an angle of the slide-link when angled for full forward or backward gear.

"Having chosen the point d, draw a vertical line $z z$ through it and at right angles to $a a$; and mark off the two points e, e^1 on each side, these being the extreme positions of the point d on the connecting-rod for front and back stroke; from these points draw lines to a point f on the vertical, so far down that the angle between them shall not be more than 90°, less is better, if there is room to allow of it (these will represent the centre-lines of the first connecting link pinned to the connecting-rod marked 1 in figs. 949 and 950). The point f, which will rise and fall with the vibration of the connecting-rod, is to be controlled as nearly as may be on the vertical line by a link pinned either forward near the cylinder at f^1, or, if more convenient, it can be pinned backward. This link, which is called the anchor link, is marked 2 in the same figures, or the point f may run in a slide.

"Next, on the valve-spindle centre-line $b b$, mark off on each side of the vertical $z z$ the amount required for lap and lead together, at g-g^1 and g-g^2; g-g^1 being 'lap and lead' for the front end of the cylinder; and g-g^2 being lap and lead for the back end of the cylinder. Then, assuming the piston to be at the front of the cylinder, and the centres of the connecting-rod to be at $h h^1$ (h^1 being the crank-pin), the point d, which we have chosen to take motion from will be at e^1, and the link pinned to the connecting-rod for transmitting motion to the valve will be at $e^1 f$. From a point on this link, which has at first to be assumed, say at j (which will be about one-third more than the half vibration of the connecting-rod, that is d to d^1), draw the centre-line of the lever 3 actuating the valve, that is joining j and g^1; the point where this line crosses the vertical $z z$ will be the centre or fulcrum of the lever, and will also be the centre of oscillation of the curved links 4 in which the blocks carrying the centre of the lever slide; this centre is marked m, and stands for both centres, which must be concentric at each end of the stroke. The function of the link e^1-f, and the attachment of the valve lever to it at j, is to eliminate the error in vibration of the lever centre m, which would otherwise arise, from the arc passed through by the lower end of that lever. Although the position of the point j may be found by calculation, it is much more quickly found by a tentative process; and to test if the assumed point j be the correct one, we mark off on each side of m, vertically, the correct equal vibration required, $n^1 n^2$, which will be the same as the vibration of the connecting-rod on the vertical line $z z$. Then apply the

distance $e^1 j$ to $d^1 j^1$ and $d^2 j^2$. Then, if the length $j\,m$ be applied to $j^1 n^1$ (measuring from j^1) and to $j^2 n^2$ (measuring from j^2), and the point m fall below $n^1 n^2$ in each case, it will be necessary to take a point on $e^1 f$ higher than j; or if, on the other hand, m falls above $n^1 n^2$, then a point must be taken on $e^1 f$ lower than j. This point will generally be found on a second trial, but the length j, m of the lever j, m, g^1 must be such that its centre m vibrates equally on each side of the centre of the quadrant, also marked m.

"The point m, as said, now represents the centre of oscillation for the links 4 and the centre or fulcrum of the lever 3. And these, as already said, must coincide, when the piston is at each end of the stroke, the lead being then fixed, and the links can be pulled over from forward to backward or any point of expansion without altering the lead. This may be taken as a test of the gear being set out correctly.

"The point g will be the point of attachment for the valve-spindle link marked 5, which may be made any convenient length, but from that length as a radius the curve of the links must be drawn from a centre m' on the parallel line $m—m'$; the angle at which this curve is set from the vertical (which is mid-gear) will give forward or backward gear—the angle leaning forward s^1, or to the front of the engine, being forward gear, and the reverse s^2 being backward gear. The centres for these curves will be found at m'' and m'''. The amount of the angle, marked on the curve of extreme vibration at s-s^1 or s-s^2, will be equal to one-quarter more than the full opening of the port at that angle (that is if 1 inch opening of port be required, then the amount of the angle $s\,s^1$ must be 1¼ inches), and the point of cut-off will be about 75 per cent. Laid out in this form the 'leads' and 'cut-offs' for both ends of the cylinder, and for backward and forward going, will be practically perfect and equal, and the opening of ports also as near as possible equal. If a longer cut-off than 75 per cent is required it is only necessary to increase the angle of the curve o beyond s^1 for forward gear, or beyond s^2 for backward gear. It will be noticed that in this gear the 'lap' and 'lead' are entirely dependent on the action of the lever, j, m, g^1, as a lever, and may be varied according to the length of $m\,g^1$. And the opening of the port (beyond the amount given as lead) is dependent on the amount of angle imparted to the curved link o, and will be, as above said, about 4/5ths of the amount of that angle from the vertical, measured on the line of extreme vibration. Instead, however, of employing a curved link with slide-blocks to guide the centre or fulcrum of the lever 3, this centre may be hung in sling-links, having their centres of suspension adjustable in the curve $m'\,m''\,m'''$, such centres of suspension representing the points for 'mid-gear,' 'backward,' and 'forward' going. All the rules for laying out the gear will, however, remain the same.

"Deviations from the above positions and proportions may be made without materially altering the correctness of the results.

"Thus, if it is found necessary to raise or lower the centre m, to clear wheels, frames, or other gear, without altering the position of the valve-

spindle centre, this may be done till the angle of *m m'* is out of the parallel of the cylinder centre-line up or down by one in thirteen (1 in 13); it is not well to go beyond this, but the lines *m m'* and *b b* will be parallel, and the position of the curve *o* for mid-gear will be at right angles to *m m'*.

Again, the point e^1 may be taken either above or below the centre-line

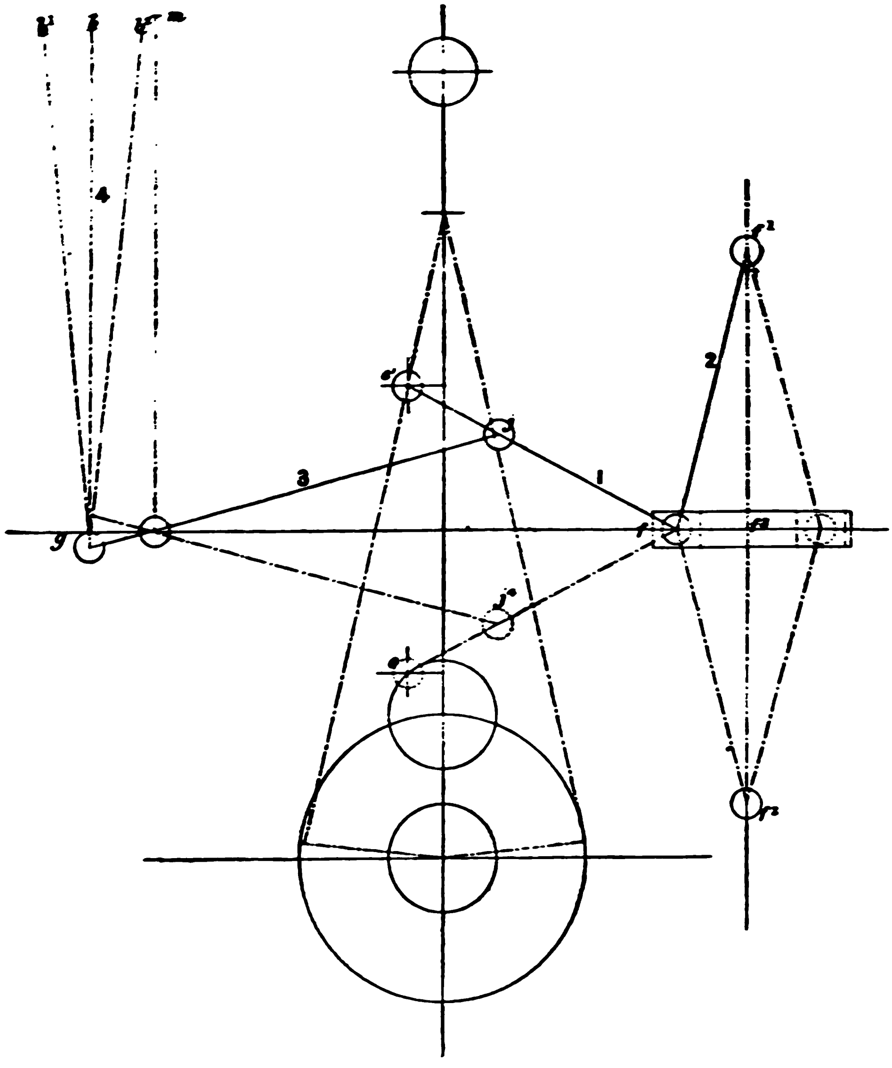


Fig. 950.—Joy Valve-gear, adapted for Vertical Engines.

of the connecting-rod, if it be wished to avoid piercing the rod, the pin at e^1 being carried in a small bush or [illegible] ck attached above or below the connecting-rod, or to a boss forged [illegible] ecting-rod.

"Again, for locomot[illegible] ls are so small that the link $e^1 f$ would come too low, [illegible] point *j*, and this point

connected by a link $l\,l$ to a small return crank p, on the crank-pin, the movement of the counter-crank being equal to that from j to j^4.

"The diagram is drawn for an engine where the centre of the crank-axle is on the centre-line of the cylinder, but if this be below, as is usual in American locomotives, then the base-line on which to construct the diagram of the valve-gear itself will be the average centre-line assumed by the connecting-rod for such lowering of the crank-axle centre, drawn from c, the middle position, to a point, say r, representing the lowered centre of the axle. The vertical $z\,z$ will be at right angles to this new base-line $c\,r$, all the other processes following.

"For vertical engines the same rules apply, by placing the diagram vertically and altering relatively the terms 'vertical' and 'horizontal.'

"While the proportions shown on the diagram give the best average results, these proportions may be varied within very wide limits, according to the requirements of the design of the engine. Thus, when the distance between the centre of the cylinder and centre of valve-spindle is small, as with a small cylinder and a long stroke, the link $e^1\,f$ may be considerably lengthened; the point j will thus be dropped, and convenient angles for all the links, &c., will be maintained, the room for the various movements being got below the centre-line of the cylinder, when it cannot be had above.

"In marine engines, fig. 950, the reverse conditions are usual, the distance between the cylinder and valve-spindle centres being abundant, and very little room available behind the engine. In this case the point e^1 may be taken out of the centre-line of the connecting-rod, so bringing all the gear so much further forward. The end of the link 1 may then be swung at f by the link 2 centred either above, as at f^1, or below, as at f^2, or it may be carried in a cross slide, f^3.

"Also, to accommodate the centre-lines of the valve-spindles of the high and low pressure cylinders (if different), one centre may be carried outwards to b^1 and the other inwards to b^2, from the normal centre-line b—this angle may be as much as 1 in 12 without affecting the accuracy of the gear. The centre-line of the quadrant at mid-gear will, however, be always at right angles to the altered vertical centre-line. In all cases it is well to keep the levers and links as long and the angles as easy as the room at disposal will allow."

TRAMWAY LOCOMOTIVES.

Chapter LXXXII.—EXAMPLES.

Steam power was first applied on tramways in 1859. It has since passed through many stages of development, and the engine has now

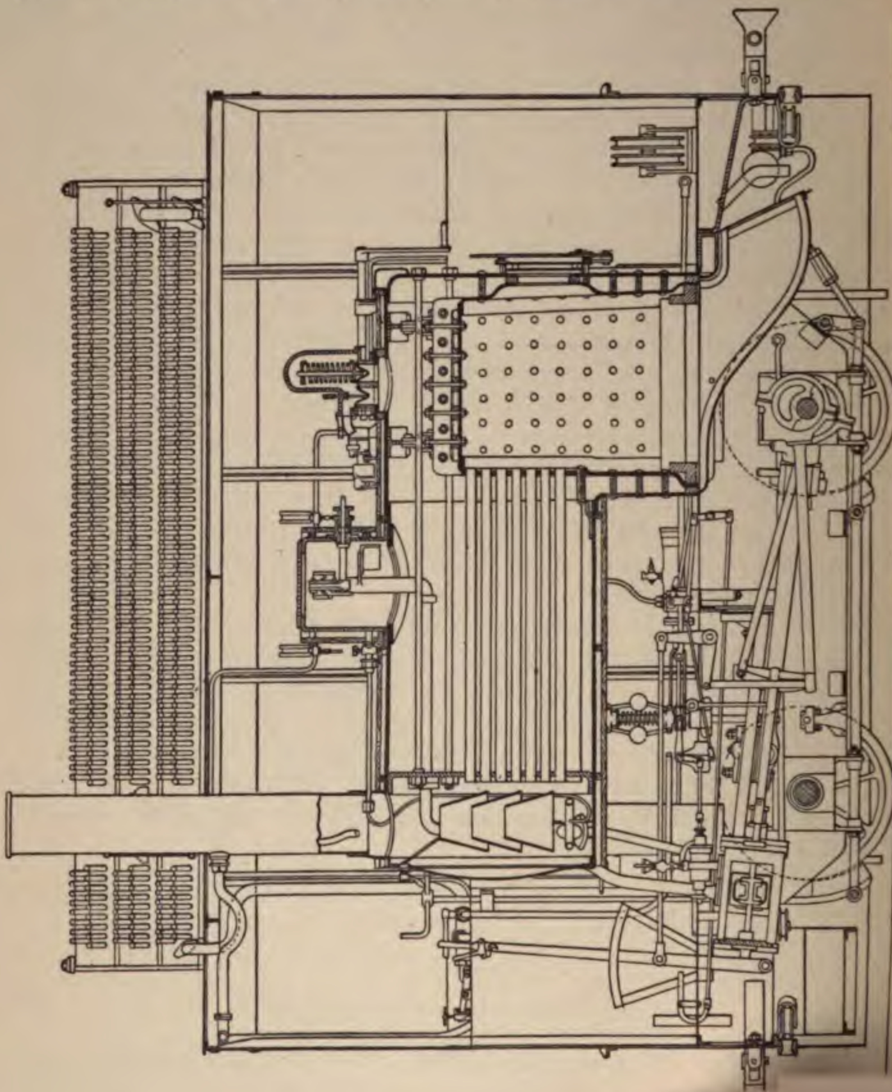


Fig. 951. Tramway Locomotive, designed and constructed by Merryweather & Sons. Longitudinal Section. Scale 1/30th.

acquired the character of a finished machine. I
Sons constructed the machinery for the first stea

in England in 1872, to the designs of Mr. Grantham. They secured their first patent in April, 1875. In one of its forms the fireless locomotive of Francq, patented in 1875, was in a great degree anticipated by Mr. L. J. Todd in 1871. Dr. Emile Lamm, in 1872, started a fireless locomotive in New Orleans.[1]

CONDENSING TRAMWAY LOCOMOTIVE.

DESIGNED AND CONSTRUCTED BY MESSRS. MERRYWEATHER & SONS, GREENWICH.

(Cylinders 7½ inches in diameter; stroke 12 inches; wheels 28 inches in diameter.)

This engine, figs. 951 and 952, is constructed for a gauge of 4 feet 8½ inches, and is fitted with two 7½-inch cylinders inside the longitudinal frame-plates. It has two pairs of 28-inch wheels, coupled, on a base 5 feet long. The cylinders are inclined to clear the coupled axle, and they are fitted with the ordinary shifting link-motion, with reversing gear at each end of the engine. The boiler is of the locomotive type, of mild steel, with a copper fire-box 2 feet 3½ inches square, and 85 brass tubes 1¾ inches in diameter outside, 4 feet long. The heating surface is 181 square feet. The working pressure is 150 lbs. per square inch. The ash-pan is specially designed to prevent the dropping of cinders or the showing of fire. It can be easily cleaned out when required. The ash-pan damper can be worked from either end of the engine. The wheels are of steel, fitted with rolled steel tyres secured by screws. The exhaust steam is con-d in an air-condenser, consisting of 404 thin 1-inch copper tubes, laid

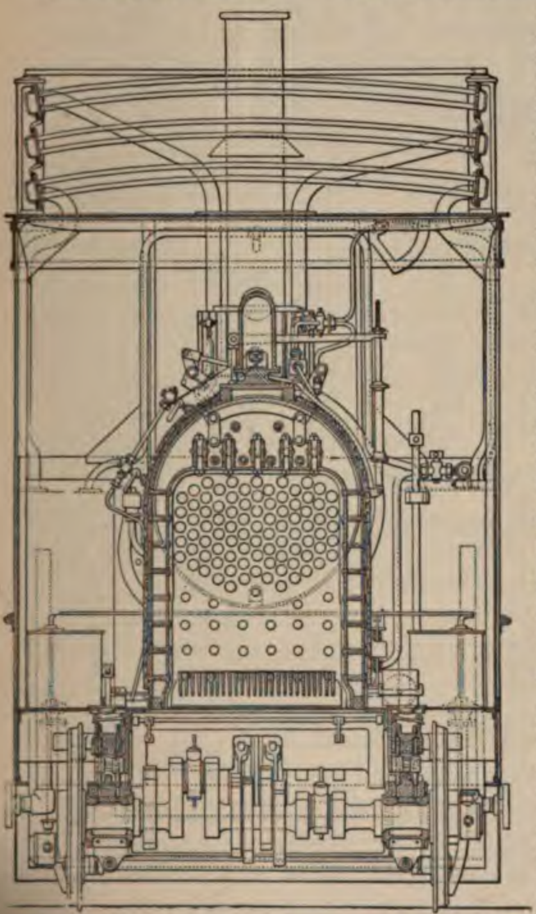


Fig. 952.—Tramway Locomotive, designed and constructed by Merryweather & Sons. Cross Section. Scale 1/30th.

[1] notice of mechanical power on tramways, see *Tramways: their Construction and* ark. London, 1878.

in three double tiers 5 feet 10 inches long, making 617 square feet of condensing surface, transversely over the roof. These are fastened by ferules at each end to longitudinal copper passages or ducts, into which the exhaust steam is discharged, and from which the steam is free to pass into the transverse tubes. The ducts are divided by internal partitions into sections in order to direct the flow of steam alternately from one side to the other.

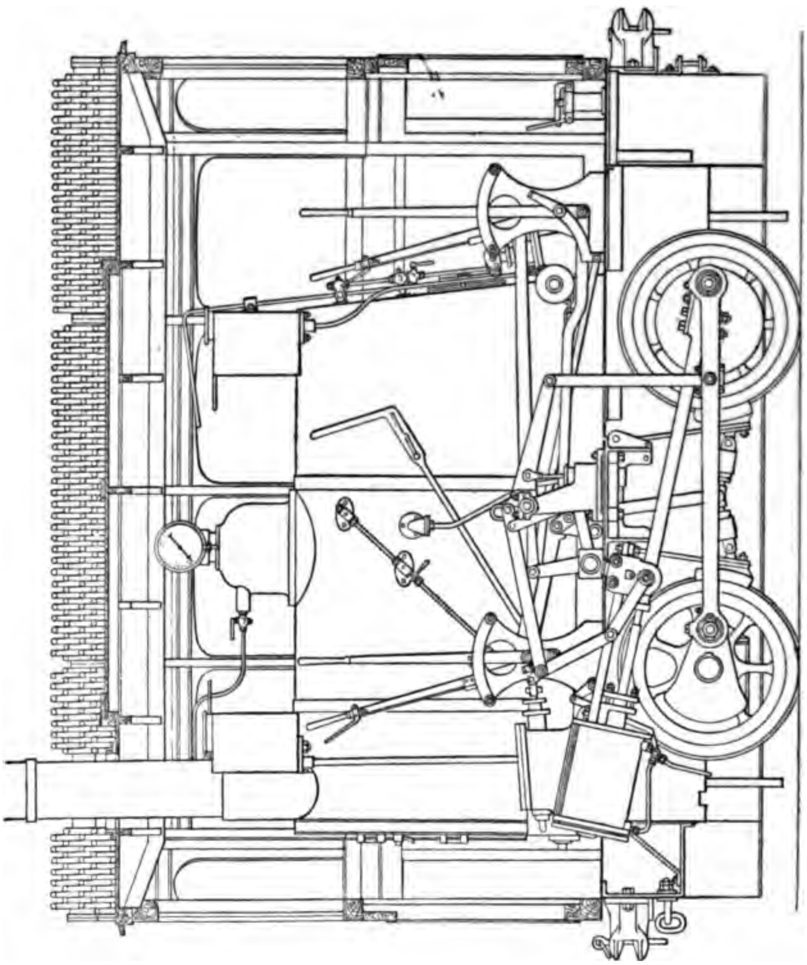


Fig. 953.—Tramway Locomotive, designed and constructed by Kitson & Co. Longitudinal Elevation. Scale 1/30th.

In order to fulfil the conditions laid down by the Board of Trade, a centrifugal governor is employed, driven by gearing direct from the driving axle, by the action of which the throttle-valve is closed when the speed exceeds eight miles per hour. Should the speed increase, nevertheless, a small steam valve opens automatically for steam to the break-cylinders, by which the break is applied. When the speed is reduced below the assigned limit, the break is thrown off. The steam-break [illegible]so be applied by the driver's foot on a treadle. All hand [illegible] each end of the foot-plate.

The engine, empty, weighs about 8 tons, and with water and fuel about 9 tons. The engine, it is stated, can take, in ordinary working, 80 passengers on inclines of 1 in 20.

CONDENSING TRAMWAY LOCOMOTIVE.

CONSTRUCTED BY MESSRS. KITSON & CO., LEEDS.

The cylinders are, in this engine, fig. 953, placed outside the longitudinal frame-plates, and as high as possible above mud and dust, protected by suitable casings. The engine is on four wheels, coupled. Kitson's valve-gear is, with the same object, employed. It is a modification of Walschaerts' valve-gear; and has already been noticed in page 33. The ends of a floating lever are linked to the crosshead and the valve-spindle; and, intermediately, at a point near the valve-spindle, the lever is pinned to the radius-link, which receives its rocking movement through an arm linked to the coupling-rod. The motion of the valve and its spindle is a compound of two movements: one, a movement directly the inverse of that of the piston, on a reduced scale, for the lead; the other, a reduced duplicate of the vertical movement of the coupling-rod, to open the port for steam. The boiler is of the locomotive type. The exhaust steam is condensed to the extent of two-thirds in a tube-condenser overhead, and one-third is discharged into the chimney.

Messrs. Kitson & Co.'s engines, as employed on the Central Tramways line, Birmingham, weigh, with water and fuel, from 9 tons to 10 tons. They can draw a large car holding 60 passengers.

WORM-GEARED CONDENSING TRAMWAY LOCOMOTIVE.

DESIGNED BY MR. W. WILKINSON.

This tramway locomotive, fig. 954, combines a few unique elements. Acting on the results of Mr. Dewrance's experiments on the evaporative activity of different parts of a locomotive boiler (noticed at page 76, vol. i.), Mr. Wilkinson designed a short locomotive boiler, having flue-tubes only 12 inches in length. His object was to maintain the water-level in the boiler practically constant, whether on level ground or on steep inclines such as 1 in 11. The tubes are not straight, but of an ogee form, in order to yield to expansion without the liability to breakage. The steam is exhausted into a condenser, fitted with tubes, also of ogee form, presenting between 200 and 300 square feet of condensing surface. The steam surrounds the tubes, and the air for cooling them is drawn through them into the ash-pan, to support combustion. The steam that remains uncondensed passes into a superheater in the smoke-box—a rectangular box fixed against the tube-plate, traversed by tubes coincident with those of the boiler, through which the burnt gases flow into the smoke-box. While running on a level line, with a heavy load, in or nearly in mid-gear, there is scarcely sufficient steam left uncondensed to cause the necessary dr[illegible] and in such a case the draught is sharpened by reducing the blast[illegible]

in applying a thimble to the top of the blast-pipe, which is done by hand with a lever.

In the fire-box, a number of Field tubes (already noticed, page 737, vol. i.) are fixed to the roof, between the roof-stays.

The power of the engine is transmitted through worm-gear to the driving-axle. The worm is double-threaded, and one turn of the axle is made for 7½ turns of the worm. The diameters of the worm and the wheel are equal, or nearly so—about 12 inches in diameter; and the obliquity of the worm-thread is so considerable that on a falling gradient

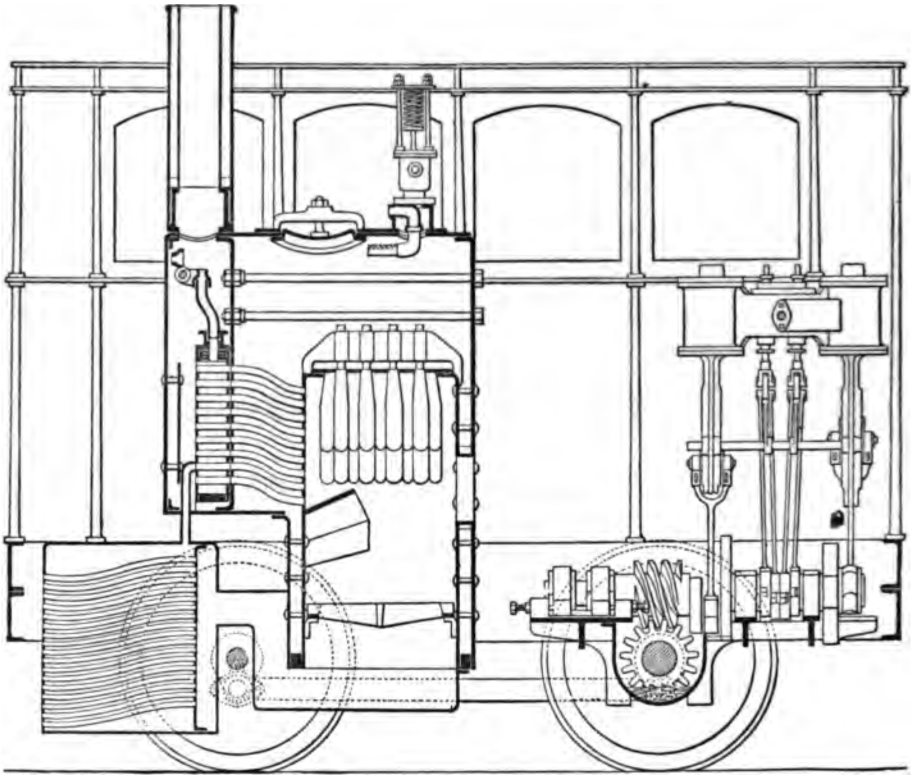


Fig. 954.—Tramway Locomotive, designed by W. Wilkinson. Longitudinal Section. Scale 1/32d.

of 1 in 70 the worm is propelled by the force of gravity. The worm is of Siemens steel, and the toothed wheel runs in an oil-bath, providing constant lubrication. The carrying wheels are 3 feet 2 inches in diameter. There are two cylinders working to a longitudinal crank-axle. It is stated that the engine can draw a loaded car weighing 3 tons, full of passengers, on a level or nearly level road, with the valves in mid-gear; the steam being cut off at 9 per cent of the stroke. At the regulation speed of 8 miles per hour, the speed of the pistons is 436 feet per minute. The engine has been worked at a speed of 16 miles per hour. The machinery is compactly placed: and the cylinders, guide-bars, valve-gear, foundation

plate, worm, and plummer-blocks can be removed for repair by undoing six bolts, and a duplicate substituted.

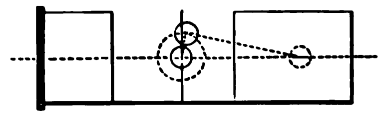
COMPOUND VERSUS SINGLE-CYLINDER TRAMWAY LOCOMOTIVES.

Messrs. John Fowler & Co. constructed compound engines for the Brighton Tramway Company, with a view to the economization of steam, and to facilitate the disposal of the exhaust steam. They had previously constructed many compound traction-engines, with which a saving of from 25 per cent to 30 per cent of fuel was effected in comparison with single-cylinder engines.

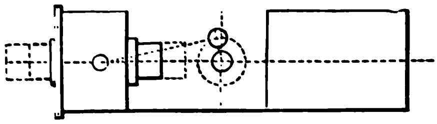
MARINE STEAM ENGINES.

CHAPTER LXXXIII.—HISTORICAL INTRODUCTION.

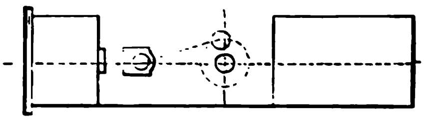
The author was enabled, in 1862, to give a general view of the marine steam engine at that time, as manifested at the International Exhibition of 1862.[1] At the Great Exhibition of 1851, paddle-engines in various forms were chiefly exhibited, and one or two screw-engines were added. In 1862, screw-engines in various forms were chiefly exhibited, and one or two paddle-engines were added. Whence it appeared that the paddle had, in the interval, been to a great extent superseded by the screw for marine propulsion—for war purposes, entirely so, for at least one obvious reason:—that the screw system of propulsion offered facilities for disposing of the whole of the machinery considerably below the level of the water-line, for the sake of general stability, and of working with comparative safety out of the direct reach of shot. But the necessity for placing the machinery in the lowest practicable position, and disposing it with its greater dimensions transversely to the hull of the vessel, has enforced the adoption of special expedients for disposing the engine compactly and equally on both sides of the main shaft, consistently with the providing of a connecting-rod of sufficient length. In the placing of screw-engines, it may be said that constructors uniformly place the cylinders at one side of the shaft, and the pumps and condensers at the other side. The divergence in detail lies in the means of connecting the cylinder with the main shaft, which has been treated in three ways—by the return connecting-rod, by means of the trunk, and by a short connecting-rod—illustrated by the annexed block elevations, figs. 655, with the same proportions of cylinder, and a central screw shaft. The method of the return connecting-rod, No. 1, gives a connecting-rod five times the length



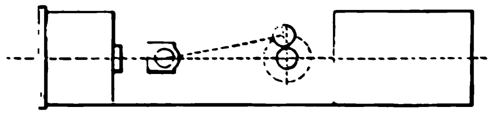
No. 1. Return Connecting-rod.



No. 2. Trunk Engine.



No. 3. Short Connecting-rod.



No. 4. Ordinary Connecting-rod.

Figs. 655.—Types of Screw Engines.

[1] See *The Exhibited Machinery of 1862*, by D. K. Clark; page 338, &c.

of the crank, and occupies the shortest width of space, transversely of the hull, admitting of the cylinders being placed closer to the crank-shaft than in other forms of engine. The trunk, No. 2, also affords a five-length connecting-rod; and the short rod, No. 3, is only three and a half lengths of the crank, though it occupies the same space as the trunk-engine, allowing for the horizontal play of the trunk. No. 4 represents an ordinary horizontal engine with a connecting-rod five times the length of the crank, occupying the greatest width of all.

For mercantile purposes, the vertical marine engine was much in favour in 1862.

In 1872, Sir Frederick Bramwell read a valuable paper on the marine engines of that time,[1] before the Institution of Mechanical Engineers. The average consumption of fuel in nineteen steamers, of which Sir Frederick gives particulars, he shows to be 2.11 pounds of coal per indicator horse-power. The working pressures ranged from 45 lbs. to 65 lbs. per square inch, and the average speed of pistons was 376 feet per minute. The most commonly accepted type of engine was the compound vertical engine, with a receiver and two cranks at right angles.

In 1881, Mr. F. C. Marshall read a valuable paper on the marine engines of the time, before the Institution of Mechanical Engineers.[2] He showed that the three great types of compound engines then in vogue were, in the order of acceptance by shipowners, as follows:—

1. The two-cylinder intermediate-receiver compound engine, having two cranks at right angles.

2. The tandem engine, in which the cylinders are in line, commonly known as the double tandem engine = two tandem engines being placed side by side, making two cranks at right angles.

3. The three-cylinder intermediate-receiver compound engine, having one high-pressure and two low-pressure cylinders, the steam from the high-pressure cylinder passing into the receivers, and thence into the two low-pressure cylinders respectively. The cranks are placed at equal angles apart round the shaft, so as to cause a balance of forces exerted on the shaft.

The compound engine, in one of these three forms, was, in 1881, universally adopted in England.

Mr. F. C. Marshall gives the following statement of the average weight of machinery, including engines, boilers, water, and all fittings ready for sea, per indicator horse-power:—

	Per I.H.P.
Merchant steamer	480 lbs.
Royal Navy	360 „
Engines specially designed for light-draught vessels	280 „

[1] See the paper, "On the Progress effected in Economy of Fuel in Steam Navigation, considered in relation to Compound-cylinder Engines and High-pressure Steam," in the *Proceedings of the Institution of Mechanical Engineers*, 1872; page 125.

[2] See Mr. Marshall's paper, "On the Progress and Development of the Marine Engine," in the *Proceedings of the Institution of Mechanical Engineers*, 1881; page 449.

	Per I.H.P.
Royal Navy, Polyphemus class	180 lbs.
Modern locomotive	140 „
Torpedo vessels	60 „
Ordinary marine boilers, with water	196 „
Locomotive boilers, with water	60 „

Average results of performance of thirty vertical compound engines are given by Mr. Marshall:—

1881.			Average.
Speed of piston, in feet per minute	From	350 to 550	467 feet.
Working pressure of steam above the atmosphere	From	70 lbs. to 100 lbs.	77.4 lbs.
Condensing surface	From	1518 to 7427 sq. ft.	
Heating surface	„	2379 to 11,045 „	
Do. per indicator horse-power	„	2.77 to 6.30 „	3.917 sq. ft.
Indicator horse-power	„	560 to 2745 H.P.	
Coal consumption in 24 hours	„	11 to 51.9 tons.	
Do. do. per I.H.P. per hour	„	1½ to 2 lbs.	1.828 lbs.
Heating surface per pound of coal per hour	„	1.647 to 3.12 sq.ft.	2.178 sq. ft.

Mr. Marshall gives the following comparative statement of the average results obtained by Sir Frederick Bramwell in 1872, with those of 1881:—

	1872.	1881.
Boiler pressure, per square inch	52.4 lbs.	77.4 lbs.
Heating surface per indicator horse-power	4.41 sq. ft.	3.92 sq. ft.
Speed of piston, in feet per minute	376 feet.	467 feet.
Coal consumed per indicator horse-power per hour	2.11 lbs.	1.828 lbs.

showing an economy equal to 13.37 per cent in weight of fuel effected in the interval.

"The quantity of steam," says Mr. Marshall, "used in the compound receiver engine and Woolf engine respectively, are stated by Mr. D. K. Clark in his *Manual of Rules, Tables, and Data* to be—

Receiver engine, 18 to 20 lbs. per indicator horse-power per hour.
Woolf engine, 20 to 21 lbs. „ „ „

It is a remarkable coincidence that the long-voyage results given in the Table I. exactly confirm Mr. Clark's figures." Mr. Marshall accepts as an average result that the Woolf engine, as usually arranged, will use 10 per cent more steam than the receiver engine for the same power. This conclusion is confirmatory of the conclusion arrived at in the investigation of the principle of the Woolf engine versus that of the receiver engine, page 443, vol. i.[1]

The area of surface condensers is usually equal to one-half of the heating surface as a minimum; that is, equal to about 2 square feet per indicator horse-power. But Mr. Marshall has found in practice that with

[1] See also *A Manual of Rules, Tables, and Data*, page 867.

1.4 square feet a steady vacuum of 27½ inches of mercury can be maintained. The experiments of Mr. B. G. Nichol[1] show that when water flowed through horizontal brass tubes with a velocity of 78 feet per minute, 533 units of heat were transferred per square foot of condensing surface per minute for each degree Fahrenheit of difference of temperature. Against this Mr. Marshall points out that in general only 200 heat-units are transferred for each degree of difference of temperature; so that, even when water flows through the tubes at the slow velocity mentioned, there is a large margin in allowance for the dirt frequently found in the tubes of condensers.

The method generally followed in practice, of passing the water through the interiors of the tubes, is usually more efficacious than the passing of the exhaust steam through them; as in the former case it is very easy to secure good circulation of the condensing water. But, in the latter case, the water may be directed fairly across the tubes with the aid of diaphragms or baffle-plates.

The marine boiler of 1881 was, in all its main features, the same as that of 1872, and of the present time:—cylindrical, flat-ended, with two, three, or four furnace-tubes opening into a back combustion-chamber; and return flue-tubes, opening into a smoke-box at the front. This form is known as single-ended. Double-ended boilers also are constructed, having furnace-tubes at each end, opening into a central combustion-chamber common to both; whence the burnt gases pass through flue-tubes to a smoke-box at each end, whence the gases are collected and conducted to a common chimney.

The first compound marine engine, introduced by Messrs. Randolph, Elder, & Co., was of the Woolf type, in which the two pistons moved simultaneously in opposite directions. Expansion was promoted in the first cylinder to the desired extent during the steam-stroke; and in the return-stroke the expansion was continued simultaneously in both cylinders down to the point of cut-off in the second cylinder. The temperature of the steam varied through the range that would have taken place in a single cylinder, except the drop that took place between the temperature at the cut-off and that of the condenser. While this type was in use, according to Mr. A. C. Kirk, the compound marine engine made but little progress: the results were no doubt better than in the ordinary single engine, but they were not what they could be. The action was materially improved by the introduction of the intermediate receiver and the separate cut-off in the second cylinder. It appears that the receiver-type of engine was introduced and brought prominently forward by Mr. E. A. Cowper, who states that "about the year 1838 a small steamboat, the Era, had a high and a low-pressure cylinder, with a pipe connecting them and cranks at right angles; in 1857 a pair of 60 horse-power engines, with high and low pressure cylinders, had a steam-jacketed receiver added to them by E. A. Cowper; in 1862 he improved the receiver, and in 1864 he read a

[1] See *A Manual of Rules, Tables, and Data*, page 476.

paper on Compound Engines at the Institution of Naval Architects."[1] By means of the receiver the range of temperature in the first cylinder was materially reduced.

It may be taken that for mercantile marine service vertical steam engines are universally employed—compounded in two, three, or even four cylinders, in which successively the steam is expanded. "Compounding" signifies specifically a combination of two cylinders for the continued expansion of steam in the first and the second cylinders successively; and although the expression is competent to cover any number of cylinders for continued expansion, the expression "triple-expansion" or "treble-expansion" is applied to the use of three cylinders successively for expansion; and "quadruple" or "double-compound" to the use of four cylinders.

In the majority of cases, when the power equals or is greater than 1500 indicator horse-power, for new ships, considerations of cargo-space do not very much interfere with the practicability of an engine-room of sufficient length to receive an engine of six bearings for the shaft, with link-motions and the valves in line with the cylinders. But, for smaller powers, it is of importance that the engines should be compactly designed, to occupy as little space as possible, in a fore-and-aft direction; particularly in cases where new triple-expansion engines are required to be fitted in old steamers that have had compound engines in them; and when it is of course of importance that the length of the engine-room should not be altered. To meet such conditions, Mr. Mudd designed triple-expansion cylinder engines with four bearings and dynamic valve-gear, of which the engines of the S.S. Coote, to be afterwards noticed, are a very good example.

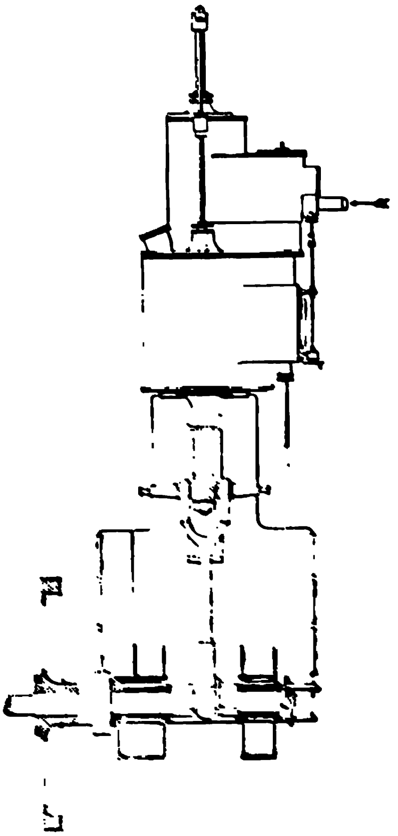


Fig. [illegible] Tandem Marine Engine [illegible]

The Tandem Compound Engine, fig. [illegible], in which the first and second cylinders are in line, with a single crank and a fly-wheel, was introduced and developed by Mr Alfred Holt, and has been adopted by some other shipowners. Tandem cylinders possess great advantages in facilitating the construction of either a triple-cylinder or a quadruple- [illegible] engine with only two cranks.

[1] See [illegible] the Engines in the Proceedings of the [illegible]

instead of three. But, as heretofore constructed, they have been attended with considerable drawbacks, notably the two stuffing-boxes required between the cylinders for the piston-rods and valve-rods; the difficulty of access to the lower cylinders for examination or for repair; and the impossibility, in many cases, of replacing packing-rings or pistons without removing the upper cylinders, which is a process involving the breaking of steam and other joints. In the engines of the Arawa and the Tainui, and like engines, constructed by Messrs. Denny & Co., and others, these drawbacks have been minimized or removed by contrivances which will be described.

The tandem system of vertical engine is more generally employed in duplicate, as the Double Tandem Engine, or two tandem engines side by side, working two cranks at right angles. It has been applied in triplicate to the City of Rome.

A modification of the simultaneously working cylinders for paddle-wheel engines, fig. 957, was introduced by Mr. John M. Rowan about the

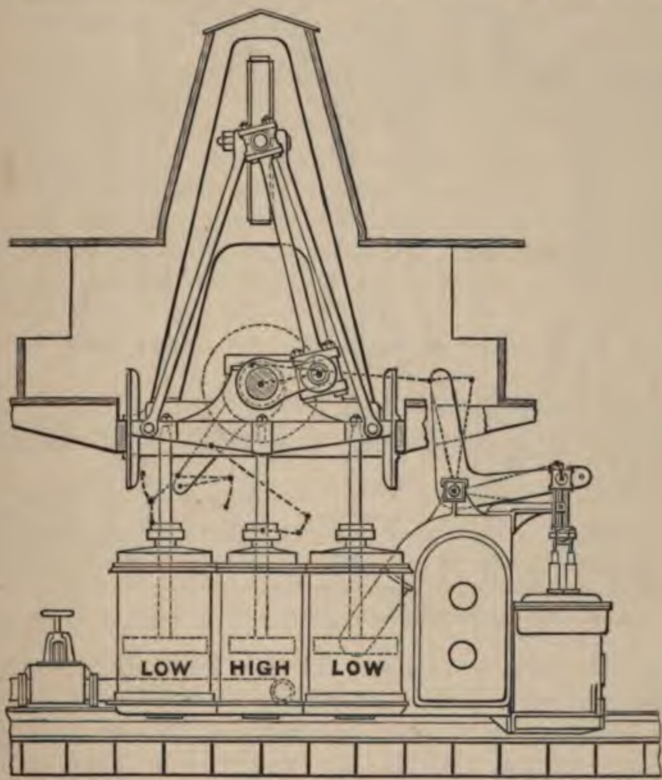
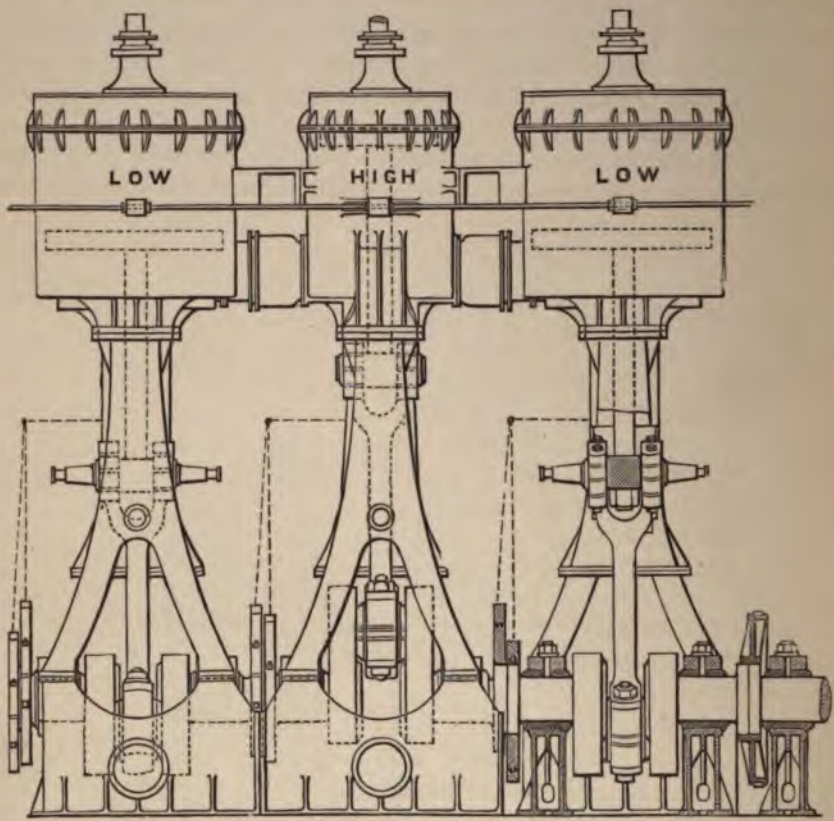


Fig. 957.—Rowan's Three-cylinder Vertical Compound Paddle Marine Engine. Scale 1/100th.

year 1861. Three cylinders, one high-pressure and two low-pressure, are placed vertically, side by side, having the three piston-rods attached to one crosshead, with a return connecting-rod, on the steeple system, applied to

drive paddle-wheels. Two sets of three cylinders each are connected to cranks at right angles on the shaft. Engines of this type were constructed by Messrs. Randolph, Elder, & Co. for the Propontis, a vessel of 1000 tons register, and they (in 1882) continued to work very satisfactorily, with steam of 130 lbs. pressure per square inch. As applied to paddle-steamers of great power, by Mr. Douglas Hebson, each set of cylinders is worked by one valve and motion, on Mr. F. C. Marshall's system, already noticed, page 30.

For screw service, the three-cylinder system, is necessarily inverted, as



Figs. 958.—Three-cylinder Vertical Compound Marine Screw Engine. Scale 1/100th.

shown in figs. 958, which illustrates the form introduced into transatlantic steamships—one high-pressure cylinder, between two low-pressure cylinders, having an intermediate receiver, and working to one shaft, with three cranks at equal angles. Several such engines are at work, and they have given satisfaction. The Arizona, of the Guion Line, was one of the first fitted with such engines. The Servia, of the Cunard Line, has like engines, with a 72-inch high-pressure cylinder, and two 100-inch low-pressure cylinders, having 6½ feet of stroke.

THE SEMI-TANDEM TRIPLE-EXPANSION ENGINES OF THE ISA.

(Cylinders 10 inches, 15 inches, and 28 inches in diameter; stroke 2 feet.)

One of the first marine engines, if not the first, constructed for triple-expansion, is that of the yacht Isa, belonging to the Royal Thames Yacht Club, the property of Mr. E. C. Healey, constructed by Messrs. Douglas & Grant, Kirkcaldy, to the specification of Mr. A. Taylor, Newcastle-on-Tyne. She is a double-masted yacht, having 118 feet length of keel; 18¾ feet entrance breadth, 10 feet 5 inches in depth, moulded; 248 tons measurement. The Isa has three cylinders and two cranks. The first cylinder is placed above the second cylinder, tandem fashion, and the two have one piston-rod, crank-pin, and link-reversing gear. The third cylinder stands beside the second cylinder, and is connected to a separate crank at right angles to the first. The cylinders are respectively 10, 15, and 28 inches in diameter, with a stroke of 2 feet, having areas as 1, 2¼, 7.84. The first and second cylinders are steam-jacketed; the third is not jacketed. Steam is supplied from one boiler, 8¾ feet in diameter, 8½ feet long, of 1-inch iron plates, having two 33-inch furnace tubes and 106 return flue-tubes 2¾ inches in diameter. The working-pressure is 120 lbs. per square inch. The crank-shaft and screw shaft are of Lowmoor scrap, having 5¾-inch journals. The surface-condenser has ¾-inch tubes, giving 350 square feet of surface. The air-pump is 10½ inches in diameter, with a stroke of 12 inches. The propeller is of gun-metal, having two blades 8½ feet in diameter, 12¼ feet in pitch. At a speed of 112 revolutions per minute a speed of 12 knots an hour was obtained. The vessel has been reported to be extremely economical in fuel.

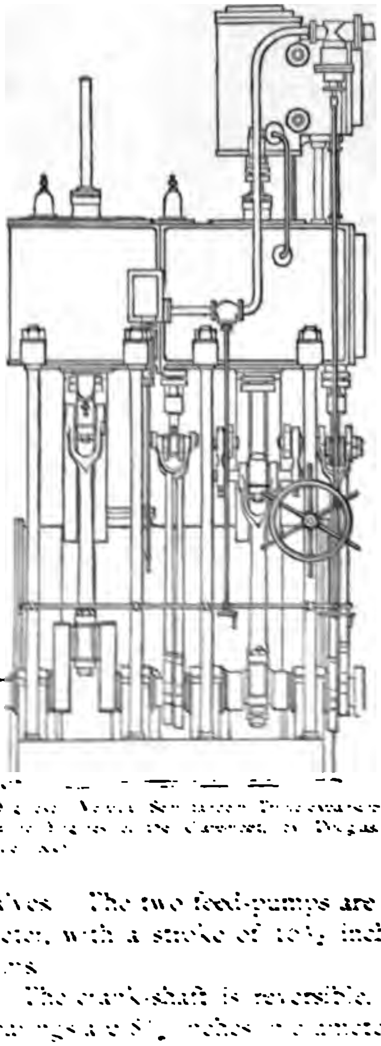
CHAPTER LXXXIV.—THE SEMI-TANDEM VERTICAL TRIPLE-EXPANSION ENGINES OF THE S.S. CLAREMONT.

(Cylinders 14¼ inches, 20¼ inches, 40 inches in diameter, stroke 33 inches.)

The S.S. Claremont is 180 feet in length, 29 feet in breadth, with 13 feet of depth of hold, carrying 800 tons of coal; of 672 gross registered tonnage, or 431 net tonnage. The engines and boilers were constructed according to the specifications of Mr. A. Taylor. The engine, fig. 959, has three cylinders, compounded in succession, like those of the Isa: the first and second in tandem, and on one crank, with one piston-rod, crank-pin, and link-motion; the third side by side with the second cylinder, on another crank, at right angles to the first. The working pressure is 150 lbs. per square inch.

The cylinders have successively 14¼ inches, 20¼ inches, and 40 inches diameter, with a stroke of 33 inches. The areas are as 1, 2.14, 7.85. The first and second cylinders are made with liners, and steam-jacketed. The first, cylinder is supported on the second by three wrought-iron

columns, socketed into each. The cover of the second cylinder is in halves, with a vertical flanged-joint, divided through the stuffing-box in order that the piston may be readily removable when required. The third cylinder is fitted with a hand starting-valve, from which the escape steam is led into the exhaust-port. The slide-valves are of cast iron. Those of the first and second cylinders are balanced, on Dawes' system; that of the third cylinder is two-ported for steam. A receiver is formed in the casing between the second and third cylinders. The steam-pipes are of 4¼-inch wrought-iron welded tubes, ⅜ inch thick, with wrought-iron flanges screwed on the pipes and brazed. The throttle-valve is 4½ inches in diameter, worked by a governor or by hand. The pistons are cored out hollow, being stiffened by ribs, and fitted with Mather & Platt's steel coils within cast-iron packing rings. The piston-rods are of forged iron, 2½ inches, 4 inches, and 4 inches in diameter respectively. The connecting-rods are 5¾ feet long, or 4.2 times the length of the cranks. They are 4¼ inches in diameter. The valve-gear consists of an ordinary link-motion.



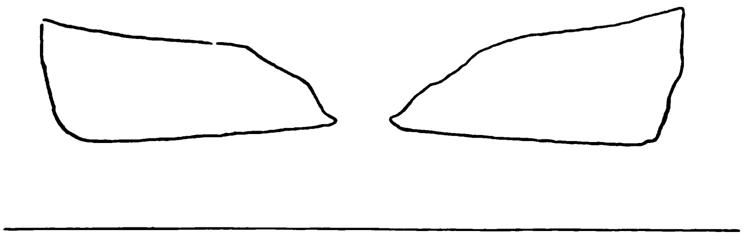
[illegible]

The surface-condenser has 650 square feet of condensing tube-surface, No. 17 wire-gauge, in 1-inch brass tube-plates, with glands screwed on cotton packing. The water is passed through two sets of tubes. The air-pump is single-acting, having 1¾ cubic feet of capacity, with Kinghorn valves. The circulating pump is double-acting, with the same kind of valves. The two feed-pumps are of gun-metal; they are 2¼ inches in diameter, with a stroke of 10½ inches. Two bilge-pumps have 3-inch brass rams.

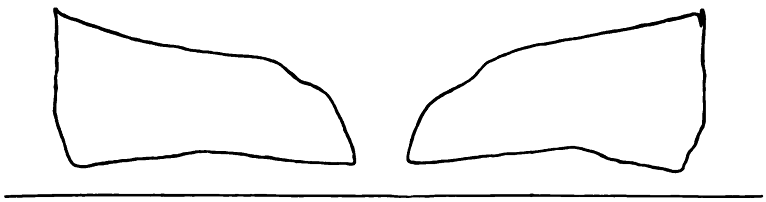
The crank-shaft is reversible, of homogeneous forged iron. The four bearings are 8¼ inches in diameter, 13 inches long, held down by wrought-iron bolts. The crank-pins are 8¼ inches in diameter, [illegible] inches long; the crank-webs are [illegible] inches by [illegible] inches. The propeller-shaft is of forged iron, [illegible] inches in diameter throughout [illegible] inches long. The [illegible] feet [illegible]. The points of the blades are set back [illegible] inches behind the after-side of the boss. The [illegible] is of forged iron, 7¾ inches in diameter.

The boiler is [illegible], in two rings of Siemens steel plates, [illegible] inches

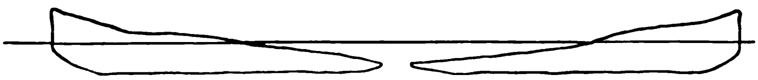
thick, 11 feet 8 inches in mean diameter, and 10 feet long inside, having three furnace-tubes 2 feet $9\frac{1}{2}$ inches in diameter, and separate combustion-chambers; and 182 iron flue-tubes, $3\frac{1}{4}$ inches in diameter outside, No. 9 wire-gauge in thickness, 7 feet long, at $4\frac{3}{8}$ inches between centres. The shell is double-riveted circumferentially, and butt-strapped and treble-riveted longitudinally, with $1\frac{1}{8}$-inch steel rivets. All rivet-holes were drilled with the plates in place; and those below the level of the axis of the shell are countersunk at both sides. The shell is surmounted by an upright cylindrical steam-chamber, $3\frac{3}{4}$ feet in diameter, 4 feet high, connected with a neck-ring. The front and the back of the boiler are each in three $\frac{7}{8}$-inch plates, flanged to take the circular shell-plates, and welded where joined at the corners. The back tube-plates are $\frac{3}{4}$ inch thick, flanged. The furnace-tubes are $\frac{5}{8}$ inch thick, the upper plates of best Yorkshire iron. The backs of the combustion-chambers are of $\frac{5}{8}$-inch Yorkshire



First Cylinder. Vertical scale 128 lbs. per inch.



Second Cylinder. Vertical scale 64 lbs. per inch.



Third Cylinder. Vertical scale 64 lbs. per inch.

Figs. 960a.—S.S. Claremont. Indicator Diagrams, at 79 revolutions per minute.

plates. The heating surface amounts to 1300 square feet. The boiler was tested by hydraulic pressure to a pressure of 300 lbs. per square inch, and in steam to 185 lbs. The shell is coated with silicate cotton and galvanized sheet-iron, No. 12 wire-gauge. The chimney is of $3/16$-inch plate, 4 feet in diameter, 40 feet high above the level of the fire-grates, fitted with a damper at the base.

At a speed of 79 revolutions, or 435 feet of piston per minute, indicator diagrams, exemplified in figs. 960, showed as follows:—

Cylinder.	Valve cuts off at.	Initial Pressure above Atmosphere.	Effective Mean Pressure.	Indicator Horse-power.
1st,....................	¾	146 lbs.	58.15 lbs.	121.18 H.P.
2d,.....................	¾	62 „	35.65 „	151.1 „
3d,.....................	½	11 „	10.45 „	172.9 „
Total indicator horse-power,.............................				445.18 „

The boiler and mountings weighed 31 tons; the engine, &c., 60 tons; total weight, 91 tons.

Mr. Taylor gives particulars of the comparative performance of the Isle of Arran and Claremont, the former designed by him in 1881, as well as the latter.[1] The vessels were constructed by the same builders, of the same dimensions, from the same model. The Isle of Arran was fitted with compound engines, having 23-inch and 46-inch cylinders, of 33 inches stroke, worked with steam of 100 lbs. pressure per square inch, from a cylindrical boiler 12¾ feet in diameter, 10½ feet long. This steamer and the Claremont were loaded in the Tyne in June, 1882, with the same coals as cargo and as fuel for the voyage. They started on the same tide for Oporto, whither the Claremont arrived in 4½ hours less time than the Isle of Arran. The Claremont returned with a cargo of 733$^{11}/_{20}$ tons of ore; and the Isle of Arran with 690 tons of ore. The total miles under steam were 3030 for the Claremont, 2596 for the Isle of Arran; and the coals consumed were respectively 100 tons and 105 tons, showing a saving of 20 per cent in favour of the triple-expansion engine of the Claremont.

CHAPTER LXXXV.—VERTICAL TRIPLE-EXPANSION MARINE STEAM ENGINES.

DESIGNED AND CONSTRUCTED BY THE CENTRAL MARINE ENGINEERING COMPANY, WEST HARTLEPOOL.

ENGINE OF THE S.S. COOT.

(Cylinders 19½ inches, 32½ inches, 53 inches in diameter; strokes 3 feet.)

The S.S. Coot is a vessel 270 feet by 37 feet, with 18½ feet mean draught, carrying 2650 tons. The engine of the Coot, figs. 961 to 963, constructed on the patents of Mr. Thomas Mudd, consists of three inverted cylinders placed side by side and bolted together, working to the crank-shaft below on four bearings. The cylinders are supported on framing placed under the first and third cylinders, bolted to a spacious sole-plate, one casting, which is formed with a flat bottom, planed on the lower side, and rests for its whole width upon the engine-seating of the hull.

The continuous flat bottom of the sole-plate is a special feature of this engine, contrasting with the ordinary system of separate front and back stool-supports. It lends itself also to a system adopted in the Central

[1] See a letter from Mr. Taylor in *The* *d Mercantile Gazette*, July 6, 1882.

works, of erecting engines on a massive level table as a temporary base. On this system, all the main bearings are bored simultaneously, and faced down the sides. Thus, whilst the bed-plate rests on a perfectly level surface, perfect alignment of the main bearings is secured, and the bed-plate, framing, and other parts remain undisturbed, until the engine is completely erected. The bed-plate is 14 feet 8 inches wide, by 11 feet from front to back, with a projection for the air-pump, generally of 1-inch metal. The main bearings are cast with the bed-plate. The engine stands 18 feet high above the base.

The cylinders are respectively 19½ inches, 32½ inches, and 53 inches in diameter, with a stroke of 3 feet; having piston-areas in the ratio of 1, 2.78, and 7.39. The cylinders are each thoroughly steam-jacketed. They are of 1⅛-inch metal, and are fitted with liners or barrels of the same thickness. The liners are tightly shrunk upon in their places. They are only secured in place, in addition, each by three screw bolts through the upper end, at the recess, which are screwed horizontally into the jacket, and are countersunk, in order to clear the piston. The liners are afterwards faced at the top, flush with the cylinder flanges, so that the cylinder-cover bears equally on the flange and the liner, and holds this firmly in place. This simple method of fixing the liners is quite satisfactory. Each jacket is supplied with steam from an independent pipe, so that any jacket can be used or disused as required, or the pressure in the jacket may be regulated. The usual pressure maintained in the first jacket is that of the boiler, 150 lbs. per square inch; in the second jacket, 80 lbs.; and in the third, 40 lbs. The cylinders are placed at equal distances of 4½ feet apart between axes, or 9 feet between the first and third cylinders. They are united together with faced bracket joints. These are not steam-joints.

The two vertical forked columns are of box section, of 1-inch metal, and are well adapted for resisting stress, both transversely and longitudinally. They are 10 feet high, 2 feet 7 inches deep horizontally at the lower end, tapering to 15 inches deep at the top. Frontwise, they have each a total width at the base of 5½ feet over the flanges: each limb of the fork is 8 inches wide, and the upper end is 14 inches wide. The forked columns are 9 feet apart between centres, as the extreme cylinders are; but they are not central to these cylinders. They are placed with their centre-lines 2 inches off the centre-lines of the cylinders, in order to make room for the eccentric gear of each cylinder respectively. They are used as oil-tanks, and can hold 300 gallons of oil. The absence of a column at the middle cylinder lays open the machinery and renders it easy of access.

The back column is of cast iron, hollow, one piece with the upper part of the condenser. They are joined to the bed-plate with the lower part of the condenser, with a horizontal flange joint.

All the frame joints are horizontal—an excellent feature in the design of the engine.

The guides for the crossheads consist of cast-iron plates bolted to the back columns, having wrought-iron pipe water-courses cast within them

for the circulation of cold water. An interspace is left between the column and the guide-plate for the circulation of air. The go-astern guides are bolted at the sides in the usual manner.

The cylinder-valves are piston-valves, placed each at the back of its proper cylinder, close to it, and so limiting the clearance-space to a minimum. The ports are formed all round the valves. The castings are of 5/8-inch metal. The valve-chambers are lined with separate hard liners, like the cylinders. The weight of the valves and spindles is supported by

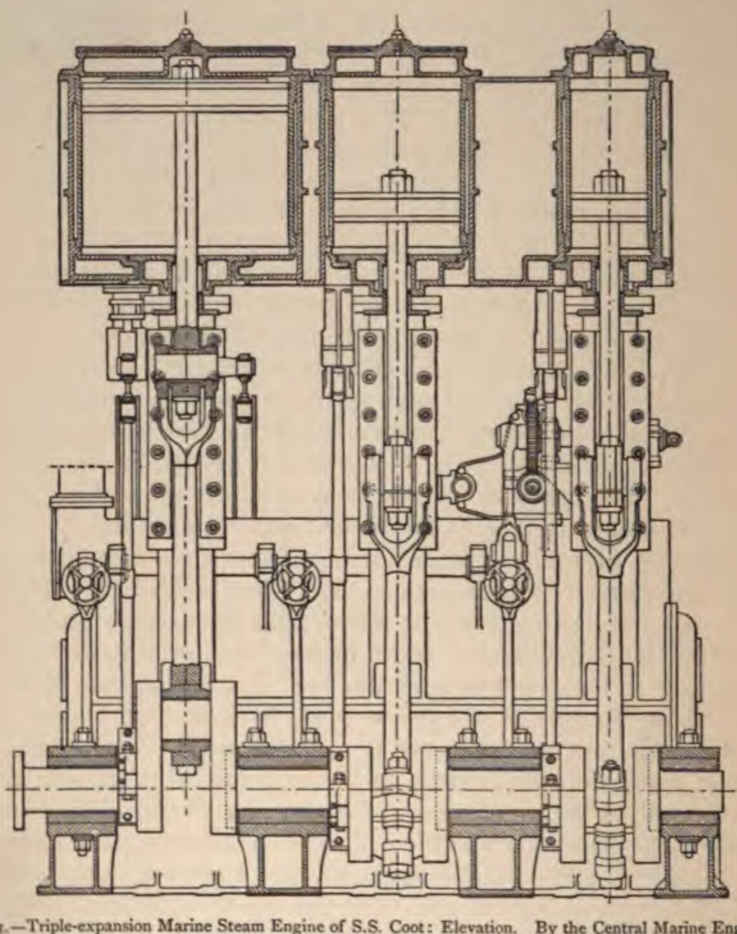


Fig. 961.—Triple-expansion Marine Steam Engine of S.S. Coot: Elevation. By the Central Marine Engineering Company, West Hartlepool. Scale 1/48th.

the pressure of the steam; so that the valves are in all respects in equilibrium, and the valve-gear has comparatively light duty. In the first and second cylinders the upper ends of the valve-spindles are, for this purpose, prolonged through the valve-box, where they are of larger diameter than at the lower ends. For the third piston valves, which contain steam between the ends of the valves, the upper end is a little larger than the lower.

	1st.	2d.	3d.
Diameter of piston-valves	10½ inches.	16 inches.	22 inches.
Maximum travel,	4¾ "	4⅜ "	8½ "
Lead, top	0 "	0 "	3/32 "
Do. bottom	9/32 "	9/64 "	9/16 "
Mean clearance at top and bottom,	8.8 per cent.	8.75 per cent.	8.1 per cent.
Throw of eccentrics,	6½ inches.	6½ inches.	6½ inches.
Normal cut-off,	60 per cent.	55 per cent.	55 per cent.
Maximum cut-off,	70 "	62.5 "	62.5 "

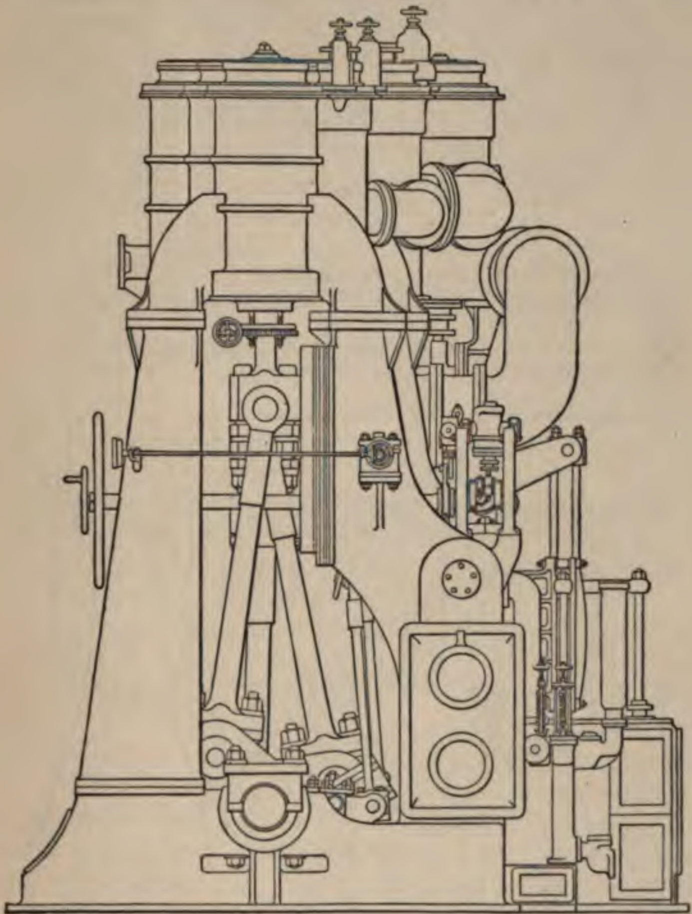
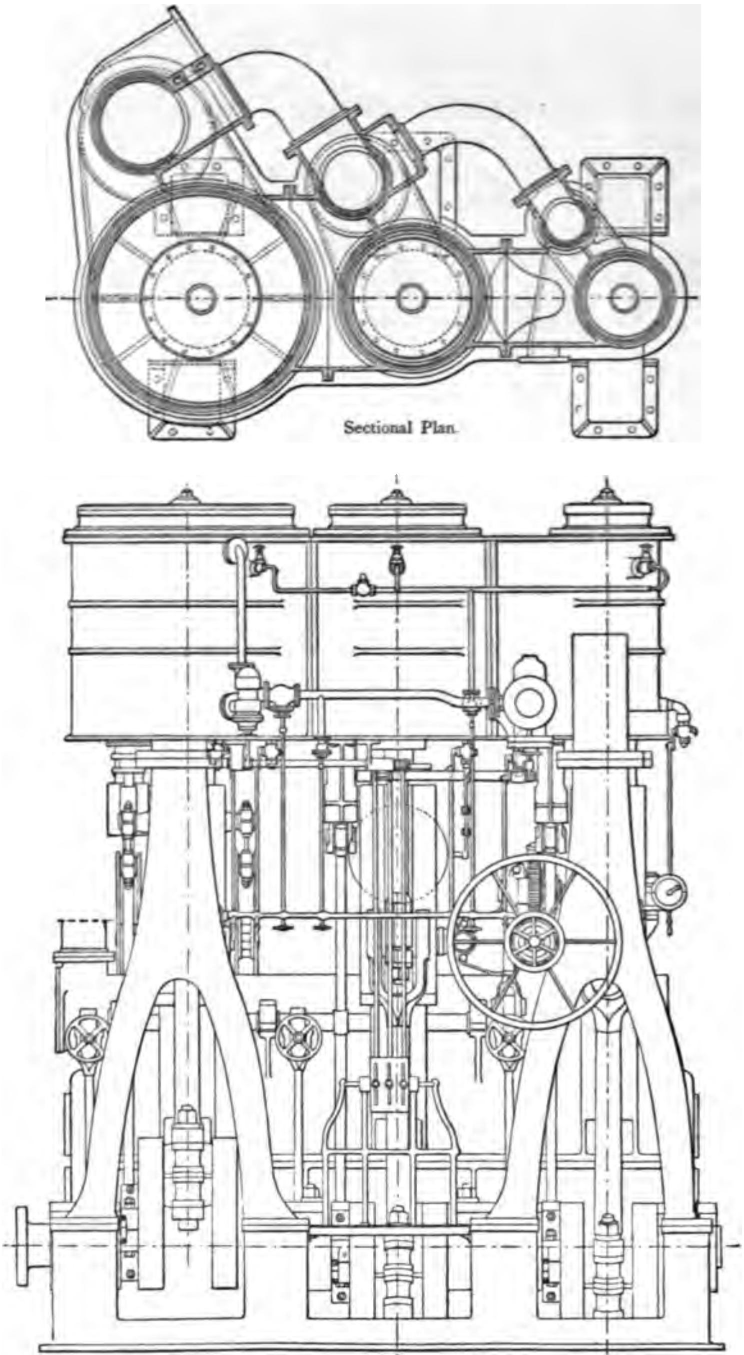


Fig. 962.—Triple-expansion Marine Steam Engine of S.S. Coot: Side Elevation. By the Central Marine Engineering Company, West Hartlepool. Scale 1/48th.

The main and branch steam-pipes are of copper, No. 4 wire-gauge, 5½ inches in diameter. The steam-pipe from the first to the second cylinder is 10 inches in diameter; that from the second to the third cylinder is 15 inches; and the exhaust pipe to the condenser is 16¼ inches.

The surface-condenser is of 1-inch metal. It has 578 condensing tubes of solid-drawn brass, ¾-inch in diameter, No. 19 Birmingham wire-gauge in

thickness, placed at $1\frac{1}{16}$ inches of pitch. They are 11 feet $11\frac{1}{2}$ inches long



Figs. 963.—Triple-expansion Marine Steam Engine of S.S. Coot: Longitudinal Section. By the Central Marine Engineer[illegible]est Hartlepool. Scale 1/48th.

between the plates, and present 1356 square feet of area. The condensing water is circulated through the tubes, the steam being condensed on the outside of the tubes. The water is circulated by means of a double-acting reciprocating pump, having a 9-inch steam cylinder, with a stroke of 24 inches. The air-pump is single-acting, 15½ inches in diameter, with a 24-inch stroke.

The crank-shaft is of forged scrap iron, excepting the crank-pins, which are of steel. The shaft is 10½ inches in diameter, and is constructed in four sections, of which three consist each of a crank and a journal. The forward cheek of each crank is recessed to receive the flange of the neighbouring section; and they are fastened together by screw-bolts. To the forward crank the forward journal is likewise bolted. The three principal sections are exact triplicates, and are interchangeable. The bearings are of great length, the two intermediate bearings being 23¾ inches long, and extending the whole distance between the first and second cranks, and the second and third cranks. The forward bearing is 15 inches long, and the aft bearing is 18 inches long. The crank-pins are of steel, hollow, 12½ inches long, 10½ inches in diameter, 4 inches wide. The crank-cheeks are tightly shrunk upon them. There is no other fastening.

The main bearings are made, not of brass as is usual, but of strong blocks of cast iron, lined with white bronze (Parsons' No. 2), held down by a wrought-iron covering plate, 2½ inches thick, and 2½-inch bolts and nuts.

On this system of extended bearings abundance of bearing surface is provided both for the journals and for the crank-pins. The journal bearing surface is effective too, as the long intermediate bearings common to two cranks take the stress of both cranks alternately. Obviously, four bearings arranged as those of the Coot are more effective than six shorter bearings brought within the same compass.

The valve-gear, figs. 964 and 965, is a modification of the so-called dynamic-motion of John Hackworth, and is worked for each cylinder by a single eccentric, forged solid with one of the crank-cheeks. The eccentric-straps are 4½ inches wide, lined with phosphor bronze, and adjustable in two directions. The valve-spindles and valve connecting-rods are of steel By the hand-wheel on the gears of the first cylinder the period of admission in this cylinder is regulated, and by the other two hand-wheels the cut-off is adjustable in the second and third cylinders, all independently.

The steam reversing-gear consists of a two-cylinder oscillating engine placed on the condenser, and working direct on the reversing-shaft. On this shaft a worm is fixed, which turns a worm-wheel which may be turned round and round in one direction, reversing the engine at each revolution.

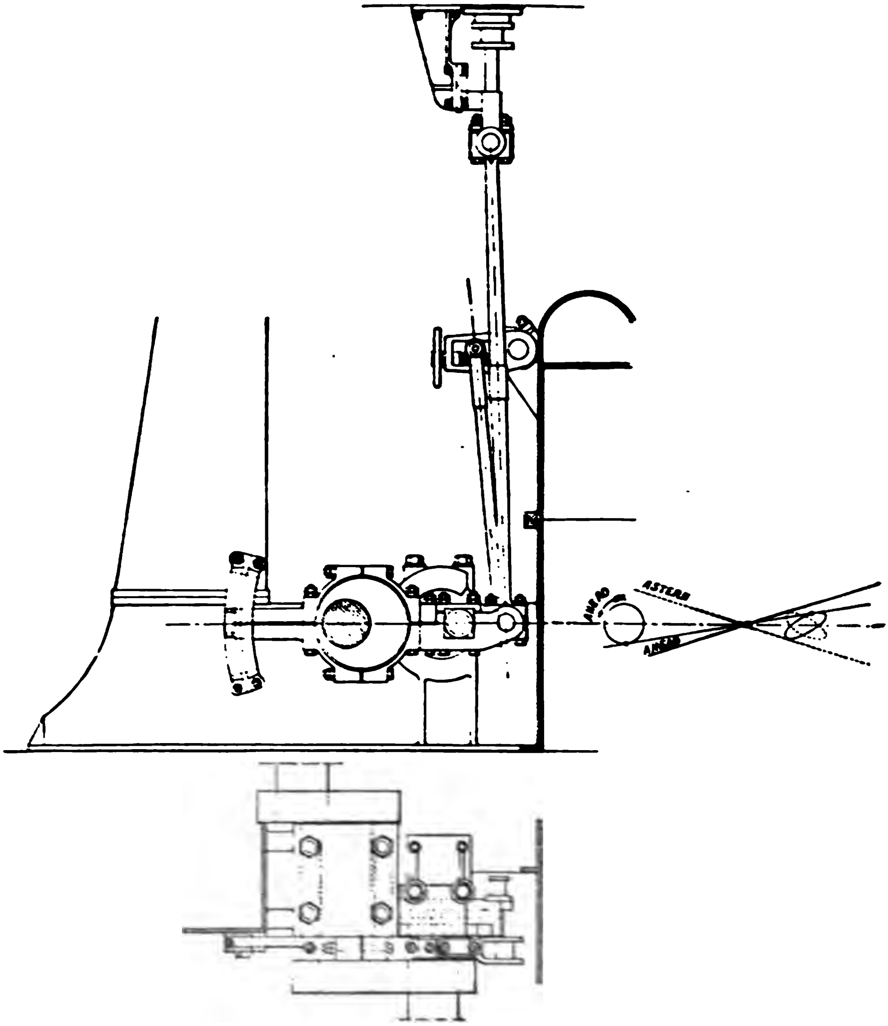
The pistons are each 7½ inches thick, fastened on the piston-rods with a nut on the ends. The piston-rods are of Siemens-Martin steel, each 5¼ inches in diameter, having each a solid-forged head and a cap fastened to the head with two bolts and nuts with brass bushes.

The connecting-rods are of forged scrap iron, 7½ feet in length, or five times the length of the cranks. They are uniformly tapered from 6½

inches in diameter at the crank-pin end, to 5¾ inches at the crosshead end. Each rod is forked to take the crosshead-pin, which is 6½ inches in diameter, with a bearing 9 inches long. The crosshead-pin of the third cylinder is prolonged at each end to give connections for working the levers by which the reciprocating pumps are worked.

All nuts are of steel.

The normal speed of the Coot's engines is 65 turns, or 390 feet of piston



Figs. 364.—S.S. Coot's Engines: Valve-gear. Scale 1 48th.

per minute. Average indicator diagrams, taken for a speed of 63 turns per minute in regular work, by calculati[illegible] ·6 indicator horse-power.

In later practice, as the engin[illegible] smoothly, Mr. Mudd works them at higher speeds. The no[illegible] a stroke of 6 feet, as in the Coot's engines, is now fixed at [illegible] feet of piston per minute,

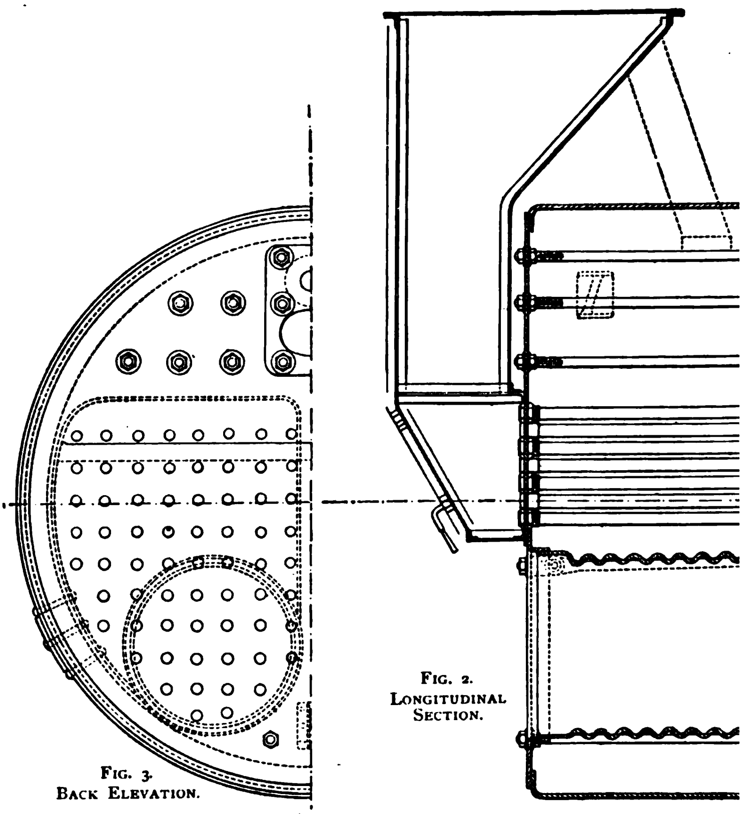


Fig. 3.
Back Elevation.

Fig. 2.
Longitudinal Section.

PAIR OF SINGLE-END BOILERS OF TI

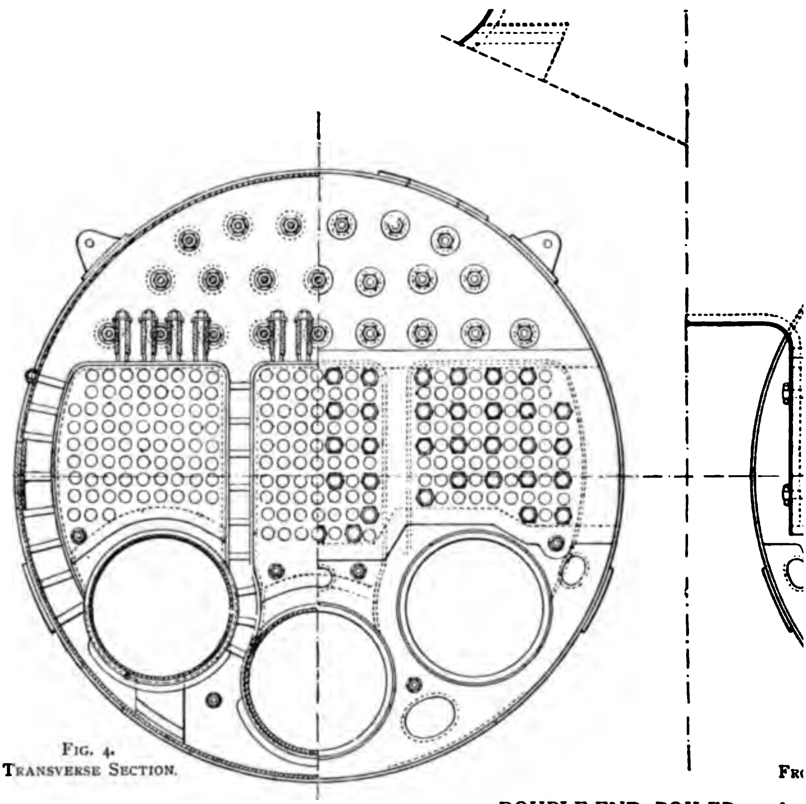


Fig. 4.
Transverse Section.

Fr

DOUBLE-END BOILER, 13 ft.


MARI
E CENTRAL MAR
COOT; 12½ ft.
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r, 16 ft.

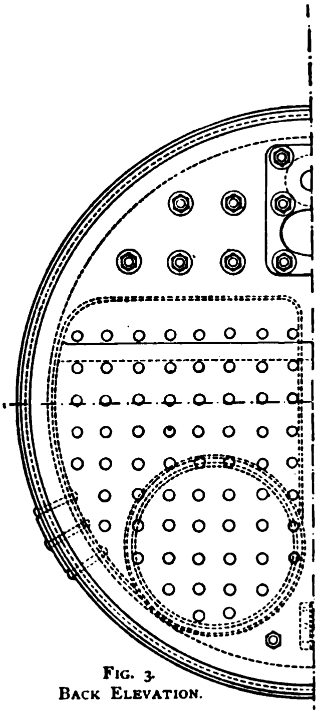


FIG. 3.
BACK ELEVATION.

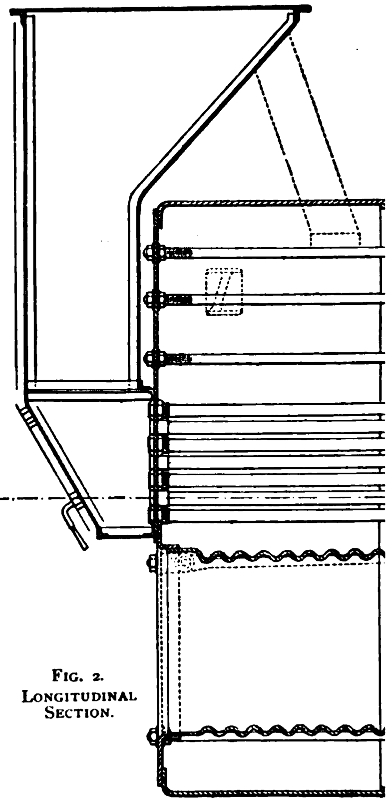


FIG. 2.
LONGITUDINAL
SECTION.

PAIR OF SINGLE-END BOILERS OF THI

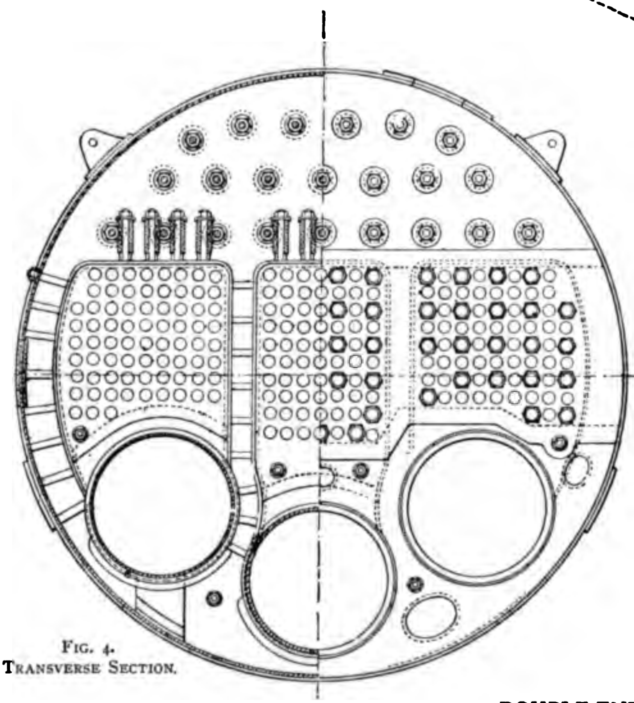
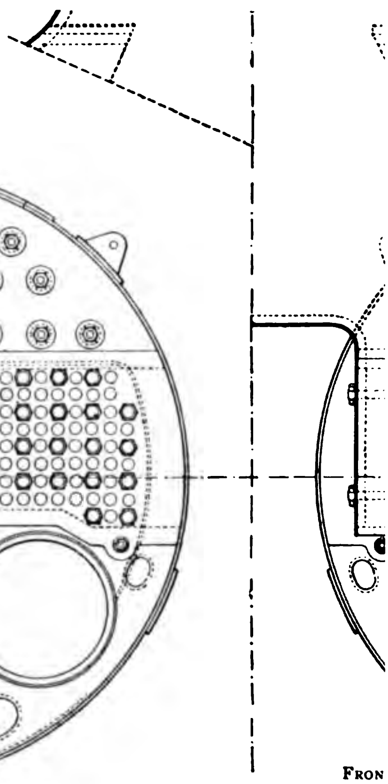
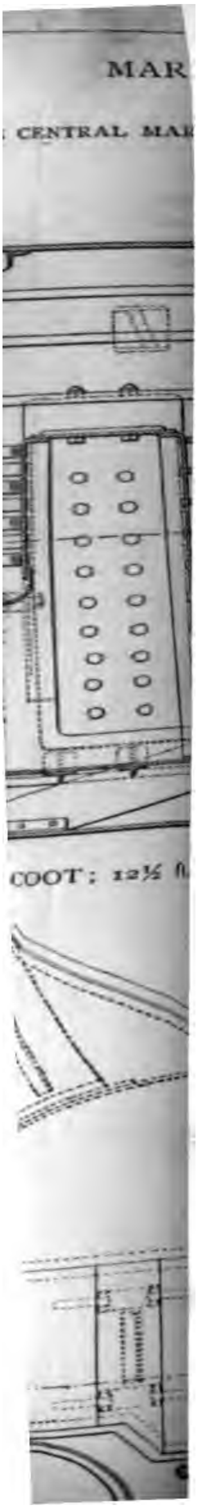


FIG. 4.
TRANSVERSE SECTION.



FRON

DOUBLE-END BOILER, 13 ft. in


CENTRAL
COOT;

according to a regulated table of speeds for different strokes drawn up by Mr. Mudd. The power is proportionally raised to 750 indicator horse-power.

The working pressure in the boilers is 150 lbs. per square inch above the atmosphere. There are two single-ended cylindrical boilers, Plate XVI. figs. 1–3, 12½ feet in diameter, 10¼ feet in length, outside measure. They are constructed entirely of steel, except the flue-tubes, which are of wrought iron. The nuts are of solid weldless steel. The shell is composed of two rings of plates, $1^{1}/_{32}$ inches thick, a back plate in two pieces, $^{29}/_{32}$ inch thick, and a front plate in two pieces, $^{11}/_{16}$ inch thick. There are two of Fox's corrugated furnace-tubes, of $^{9}/_{16}$-inch plates, 46½ inches in diameter outside the corrugation, 43½ inches at the plain portion. They open into two combustion-chambers at the back, one to each tube, 2 feet 4½ inches long at the top, of ⅝-inch plates, except the front or tube-plate, $^{11}/_{16}$ inch, from which there are 86 flue-tubes, 3¼ inches in diameter outside, from each chamber to the smoke-box at the front.

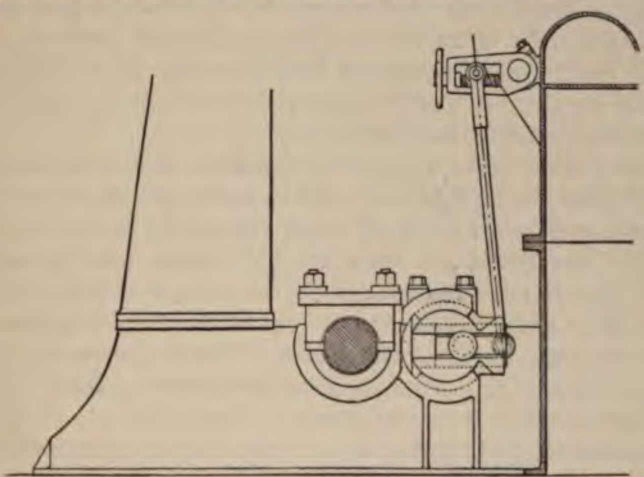


Fig. 965.—S.S. Coot's Engines: Valve-gear; Eccentric-strap removed, showing Banjo and Slider. Scale 1/40th.

The ring-plates are flanged at each end, to take the end plates, which are plain discs, and are applied direct to the flanges. The process of manufacture is as follows, in the words of Mr. Mudd:—"After the shell-rings are bent to the circle, we weld each joint by means of a glut for a distance of about 18 inches from the edge; that is, at the edge which curves towards the end of the boiler. We now have a ring, one edge of which is a complete unbroken circle of metal. We now, by means of a furnace and hydraulic pressure, flange this edge inwards all round—a severe test of the welding. Then, having fixed the several pieces of the flat end plate in their proper relation to each other, so as to form a circular disc, the ends of the joints in it are welded for a length of about 12 inches from the edge—each end plate thus presenting an unbroken edge all round. This end disc can be riveted to the flanged shell-plate without difficulty, and

without the slightest chance of the material being locally strained in drawing the two parts together. This is one of the most important advantages of the new plan of construction. I contend that when the end-plate is flanged and placed inside the rings of the shell-plates, as is commonly done, it is quite impossible for the ring to be a sufficiently tight fit on the flange of the end-plate to be riveted up tightly all round, without puckering somewhere, and so setting up local strains. These are, to my mind, a likely cause of some of the failures in steel shell-plates that have occurred." When the ring is welded and flanged, and ready for drilling, it is placed in a large stove, having the flange downwards, and is heated by large fires beneath it, in order that any unequal straining of the metal due to the treatment may be eased at a red heat.

The longitudinal seams are double-strapped or double-welted at the unwelded portions, between the end welds, as shown in Plate XVI.; thus obviating the riveting together of three plates—an important consideration in view of the great thickness of plates now necessary. The ends of the straps stopping short clear of the rounding and flanging at each end of the shell, they can be effectively caulked inside and outside; and as the end seam of rivets is on this system entirely at the front, it is more freely accessible for repair at the lower part than when, in the usual manner, it is placed on the circumference of the ring.

The double strap joint for the longitudinal seams is made with two plates, $1\frac{1}{32}$ inches thick, $15\frac{1}{2}$ inches wide, and triple zigzag riveting. The rivets of each longitudinal row of rivets are at $6\frac{7}{8}$ inches of pitch. The centre-lines of the outermost rows are $1\frac{5}{8}$ inches from the edges of the plates. The circular seam between the two rings of plates has 5 inches of lap, and is double-riveted, at 4 inches of pitch longitudinally, and $1\frac{1}{2}$ inches from the edges of the plates. The ring-seam and the seams of the end-plates and ring-plates are double-riveted to the ring-plates with $1\frac{1}{32}$-inch rivets, at $3\frac{5}{8}$ inches of pitch in line. The pieces of each end-plate are joined with $4\frac{1}{2}$ inches of lap, and double-riveted with $1\frac{1}{32}$-inch rivet holes at $3\frac{5}{8}$ inches of pitch in line.

The sectional area of the rivets is, according to Lloyds' formula, 87.6 per cent of that of the solid plate; and the net sectional area of plate at the rivet-joint is 84.70 per cent. According to Mr. Mudd's usual practice, the rivet percentage is a little in excess of the plate percentage.

The plates of the combustion-chamber are riveted together with $\frac{7}{8}$-inch rivets at $2\frac{1}{4}$ inches of pitch. The bottom of the combustion-chamber is welded to the corrugated furnace-tubes, and there is no seam there—a situation in which seams generally are very troublesome—except the seam connecting the bottom plate with the back plate. The flat bottom is stiffened with two angle-irons riveted to it, one of which is applied at the weld, and strengthens it. The water-space at the back is $6\frac{1}{2}$ inches wide at the bottom, widened to [illegible] inches at the top. The lateral spaces are $7\frac{1}{2}$ inches wide, and the middle [illegible] $6\frac{3}{4}$ inches. The furnace-tubes are each 7 feet long, and they are [illegible]ted to the tube-plate with $\frac{7}{8}$-inch

rivets at $3\frac{1}{4}$ inches of pitch in line, and to the shell-plate at $3\frac{1}{16}$ inches of pitch. They have fire-grates 5 feet long, 44 inches wide. The lateral spaces in the corrugations are not filled up.

Of the 86 flue-tubes from each combustion-chamber there are 28 stay-tubes $\frac{5}{16}$ inch thick, screwed at the rate of 10 threads per inch, and riveted at the smoke-box end; and 58 plain tubes, No. 9 imperial gauge in thickness. The tubes are at a pitch of $4\frac{1}{2}$ inches, and are 7 feet long, measured over the plates.

The combustion-chambers are stayed to the shell with $1\frac{3}{8}$-inch screwed bolts, at $8\frac{1}{8}$ inches of pitch, cup-headed. The top of each chamber is stayed by five stay-bars $8\frac{1}{4}$ inches deep. The upper parts of the ends of the shell are stayed by 16 stay-bolts with double-nuts at each end, pitched at $13\frac{1}{2}$ inches apart, of which four central bolts are $2\frac{3}{8}$ inches in diameter, and the remainder are $2\frac{1}{4}$ inches. There are, in addition, two $2\frac{1}{4}$-inch stay-bolts for the lower part of the end-plates—one on each side of the mud-hole, fixed with double-nuts at each end; and there are two $2\frac{1}{2}$-inch iron bolts to stay the back tube-plate to the front end-plate. These are of iron, because they must be welded—welding in steel stays not being allowed by Lloyds'. They are pinned to studs riveted to each plate. The back end-plate is stayed to the bottom of the shell by a $\frac{1}{2}$-inch gusset-plate, 12 inches wide, fastened by 1-inch stud-bolts and nuts, screwed through the plate, with nuts to join up the angle-irons.

An objection may be made to boilers constructed with the flat circular seams at the ends, as described, that the flanging of the ring-plates causes the furnace-tubes to be placed at a little higher level within the shell to clear the flange than in boilers constructed with flanged ends; so causing a loss of heating surface by the sacrifice of a row of flue-tubes. But, it may be argued, on the contrary, that the additional water-room at the bottom of the shell is of advantage for better circulation.

Mr. Mudd has succeeded in forming the manhole of the boiler by flanging the solid plate. The flanged edge is faced, and enters a corresponding recess cut by an ovalling machine in the face of the cover, which is a flat plate of steel. The jointing material, as a complete oval ring, is lodged in the recess, and thus is held between two faced surfaces.

The smoke-box of each boiler is of $\frac{3}{16}$-inch plates, and rises $2\frac{1}{2}$ feet deep in front of the boiler. The two boxes are united at the upper part, to join the funnel or chimney, which is of $\frac{1}{4}$-inch plates at the bottom and $\frac{3}{16}$-inch above. It is 6 feet in diameter, 51 feet high above the level of the fire-grates.

The area of fire-grate is 36.6 square feet for each boiler; and the heating surface is 1295 square feet for each boiler, or 35.4 times the grate-area. The heating surface is calculated for the outer surface of the flue-tubes between the plates; all the area of the back tube-plate, but none of the front tube-plate; the area of the combustion-chambers and the furnace crowns above the level of the axes or centre-lines of the furnace-tubes.

The actual consumption of coal is from 10 tons to $11\frac{1}{2}$ tons per day,

according to the quality of the fuel, when it is estimated that 650 indi-

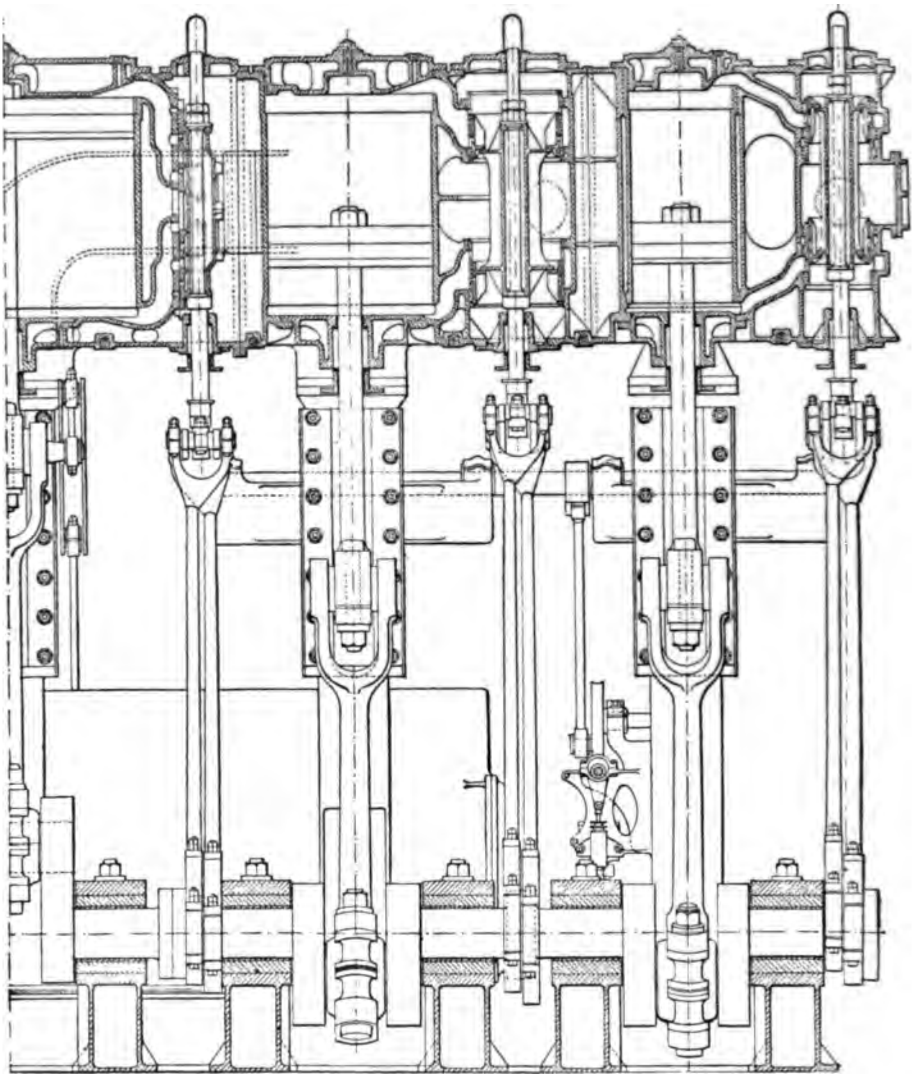


Fig. 966.—Triple-expansion Marine Steam Engines of S.S. Maryland: Longitudinal Section. By the Central Marine Engineering Company, West Hartlepool. Scale 1/48th

cator horse-power was exerted, equivalent to from 1.44 pounds to 1.65 pounds per indicator horse-power per hour, and at the rate of 933 pounds per hour, or 12.75 pounds per square foot of fire-grate area.

On her first voyage round the Mediterranean Sea the Coot was in company of a sister ship fitted with compound engines, belonging to the same owners, carrying rather less cargo, and making a voyage less by 600 miles, at about equal speed. The Coot consumed 170 tons less coal than the other vessel, representing a saving of nearly 25 per cent.

A pair of double-ended boilers is illustrated by Plate XVI. figs. 4–6,

showing the usual method of joining the circular and end plates by flang-

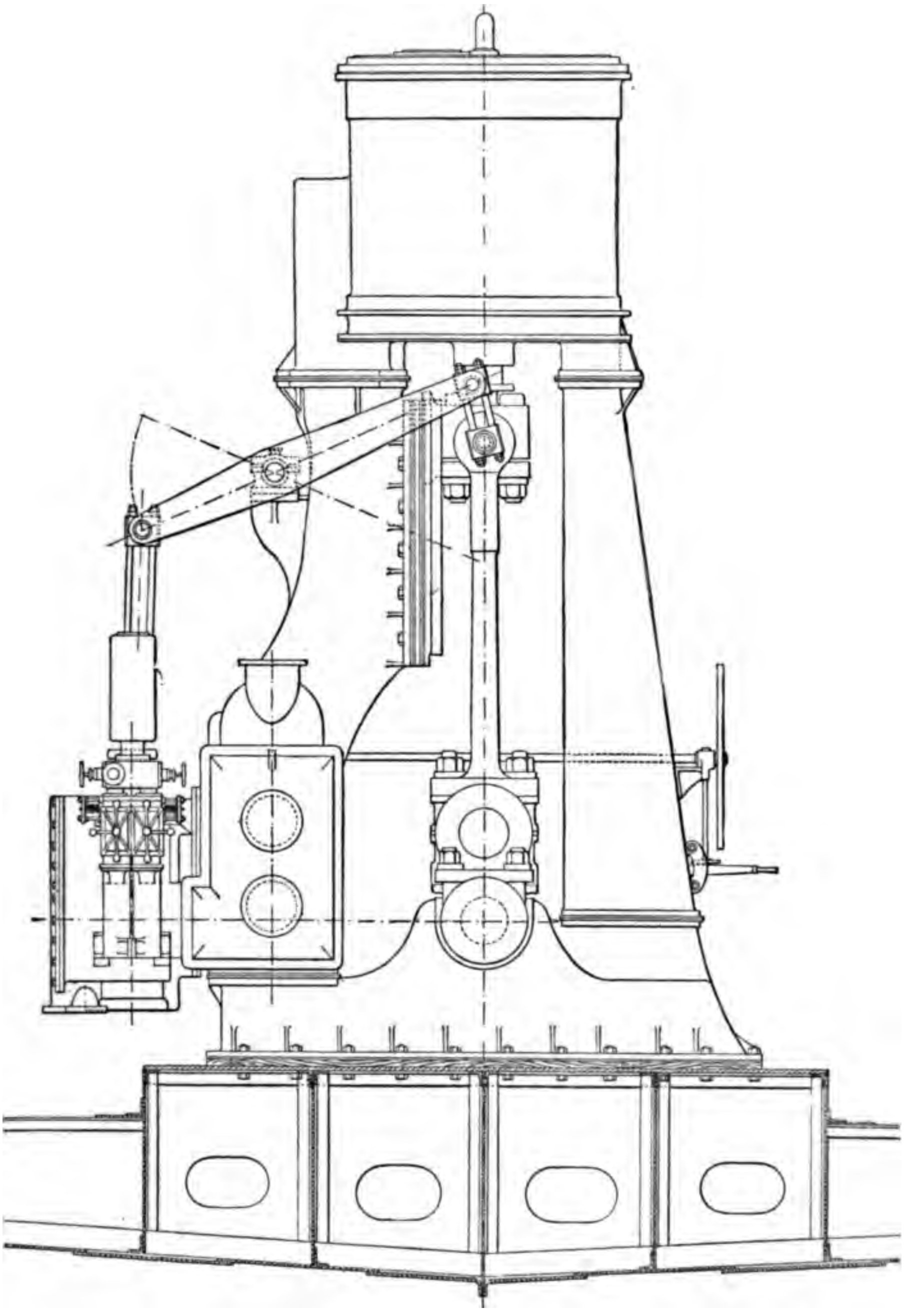


Fig. 967.—Triple-expansion Marine Steam Engines of S.S. Maryland: End Elevation. By the Central Marine Engineering Company, West Hartlepool. Scale 1/48th.

ing the end-plate. The boilers are designed for a working pressure of

150 lbs. per square inch. The shell has 13 feet mean diameter, and is 16 feet 7⅞ inches in length outside. The circular plates are in three rings, $1^1/_{16}$ inches thick; the end-plates are $^{29}/_{32}$ inch thick, flanged to fit within the circular plates; the flue-tube plates are $^{15}/_{16}$ inch thick. The riveting of the shell is shown in Plate XVI. There are at each end three corrugated furnace-tubes, of ½-inch metal, 40 inches in diameter externally, 37 inches internally, and about 6 feet 7 inches in length, opening into three combustion-chambers in the middle, 3½ feet long—two furnace-tubes to each chamber. Over each furnace-tube the draught returns to the smoke-box at each end of the boiler, through iron flue-tubes 3¼ inches in diameter outside, 70 tubes over each middle furnace, and 73 over each side furnace, 6 feet $6^{15}/_{16}$ inches long measured over the tube-plates. Of these, 21 tubes of each group are employed as stay-tubes, $^5/_{16}$ inch thick; the other tubes are No. 8 wire-gauge in thickness.

The stay-nuts of the combustion-chamber, which are exposed to flame, are made ¼ inch deeper than usual to receive a disc of iron or of steel, ¼ inch thick, riveted into its place. This is a cheap and effectual method of making capped nuts; and by that means the end of the stay-rod is protected from the action of the flame, and the whole of the thread is maintained in good condition. When the nut becomes burnt it can be unscrewed and replaced by a new nut.

The fire-grates are 5 feet long, in two lengths of fire-bars, the mean width, allowing for the corrugation, being 3 feet 2 inches. The area of fire-grate for six furnaces is 95 square feet, or 190 feet for twelve furnaces. The heating surface in each boiler is 2802 square feet, or 5604 feet in two boilers, or 29.5 times the grate-area.

The normal water-level is 6 inches above the combustion-chamber.

The factor of safety for the engine-work is 12 for the ends of the piston-rods below the threads, calculating with 20 lbs. per square inch as the initial load on the third piston. Most other parts have a somewhat higher factor than 12. The boilers are proportioned according to Lloyds' rules, and the safety-factor is 5, or a little more.

ENGINES OF THE S.S. MARYLAND.

(Cylinders 25⅜ inches, 42 inches, and 68 inches in diameter; stroke 45 inches.)

The Maryland is a steamer of 6425 tons displacement. The engines, figs. 966 and 967, resemble, in general style, those of the Coot, just noticed. They are vertical, fitted with ordinary link-motion reversing gear, and with the crank-shaft constructed of three similar pieces, interchangeable, bolted together. Each piece comprises a complete double-crank, with two journals —the whole shaft working in six bearings. The shaft is of steel, 13 inches in diameter, in bearings 18 inches long. The crank-pins are 13 inches in diameter, and give journals 16 inches long.

The cylinders, three in number, are respectively 25⅜ inches, 42 inches, and 68 inches in diameter, with a common stroke of 45 inches: in the capacity-ratios of 1, 2.74, and 7.18. The first and third cylinders are

supported direct on cast-iron framing similar to that already described for the S.S. Coot, and the second cylinder is supported by a pair of wrought-iron columns. The first cylinder only is steam-jacketed on the case. The first and second cylinders are fitted with piston-valves, and the third cylinder with a triple-ported slide-valve.

By the aid of steam reversing-gear the engines may be reversed in five seconds, without shock. By steam turning-gear the engines may be turned a complete revolution in five minutes.

The engines are supplied with steam of 150 lbs. pressure per square inch in the boiler, and they can be worked to indicate about 1800 horse-power. At sea they are capable of maintaining 1700 horse-power, going at the rate of 11 knots per hour.

Chapter LXXXVI.—FORCED DRAUGHT IN MARINE BOILERS.

COMPRESSED-AIR CHIMNEY BLAST.

Artificial draught—a draught produced by mechanical means, in addition to, or independent of, the natural draught in a chimney—has for many years been practised here and there, by means of an exhausting fan in or near the chimney, and also by means of one or more steam jets suitably placed in the chimney, acting by induction.

In or about the year 1878,[1] a blast of compressed air in the chimney was made the subject of experiment by M. Bertin. He estimated from the results obtained that the quantity of steam consumed for compressing air to act as a blast in the chimneys of steam boilers, amounted to only one-tenth of the quantity required when discharged direct into the chimney. The air-compressor employed by him consisted of two air-cylinders 24.4 inches in diameter, and a direct-action 9-inch steam-cylinder, with a stroke of 15¾ inches, making 65 double strokes per minute. The compressed-air blast was tried on one of the two boilers of the "Résolue," having 43.2 square feet of grate area, 1216 square feet of heating surface, flue-tubes 7½ feet long; volume of water, 445 cubic feet; volume of steam, 222 cubic feet; section of ash-pits, 8.17 square feet; section of chimney, 6.08 square feet; height of chimney above the level of the fire-grates, 55¾ feet; load on safety-valves, three atmospheres. For the purpose of measuring the volume of air for supplying the boiler, the compartment containing the engines and boiler was completely closed to the atmosphere, except by one passage of 9.80 square feet of area, through which the whole of the air for supplying the boiler was passed. As the experiment was confined to one of the two boilers of the Résolue, the chimney was divided vertically into halves; and the half which was used was subdivided into two quarters, to each of which was devoted one blast-nozzle, from which compressed air was discharged upwards. With two nozzles, having respectively the sectional areas 4.6 and 11.6 square inches (30 and 75 square

[1] *Bulletin de la Société d'Encouragement*, 3d series, vol. iv. page 529.

centimetres), equal duties in velocity and volume of blast were performed for equal expenditures of power. The following experimental deductions were made, when the engine was working to 18 horse-power:—

Compressed-air Blast in the Chimney: Résolue.

Section of nozzles	10	20	30	40	50	75	sq. centimetres,
or	1.55	3.08	4.6	6.2	7.7	11.6	sq. inches.
Velocity of air entering stokehold	26.6	27.2	27.9	28.5	29.5	29.5	feet per second.
Pressure of compressed air	10.7	7.2	5.6	4.9	4.3	3.6	feet of water.
Effective mean pressure of steam in cylinder of blowing engine,	4.77	3.71	3.11	2.72	2.48	2.25	atmospheres.
Revolutions per minute	51	65.5	78	89	98	108	turns.

The velocities here noted comprise the element of velocity, 19.7 feet per second, due to the natural draught.

The fuel consumed and the power exerted, with nozzles of 4.6 square inches, were as follows:—

Table No. 186.—Compressed-air Blast on the Résolue: Horse-power Developed.

Horse-power of the Blowing Engine.	Horse-power of the Engine of the Résolue.	Coal Consumed per hour. Anzin Briquettes.	Coal per Indicator Horse-power per hour.	Water Evaporated per Pound of Coal.
I.H.P.	I.H.P.	pounds.	pounds.	pounds.
0.00 Natural draught	57.5	213	3.72	10.77
0.96	88.8	289	3.26	8.82
2.00	100.5	315	3.12	8.00
3.00	106.1	321	3.04	7.82
4.20	118.8	348	2.93	7.82
5.00	119.8	374	3.12	7.53
6.00	127.9	400	3.12	7.00
7.40	135.7	420	3.10	7.03

From this table it appears that the fuel consumed and the power developed by the main engine were doubled by the employment of the compressed-air blast, the power required for which did not exceed 5 per cent of the power of the engine; but that the evaporative efficiency, or the water evaporated per pound of coal, was considerably reduced.

The rates of combustion and of evaporation were also increased by completely inclosing the stokehold, and blowing air into it with a powerful fan, so as to maintain a pressure or plenum of from 4 to 5 inches of water.

FORCED DRAUGHT WITH INCLOSED STOKEHOLDS.

Forced draught with inclosed stokeholds is in common use in the navy. A horizontal ceiling is erected about 10 feet or 12 feet above the floor-plates, extending from the coal-bunker bulkheads to the fronts of the boilers; from this ceiling vertical screen-plates are extended down between and at the ends of the boilers to meet th[illegible]-bearers of the boilers, and

worked around the fronts of the boilers, to inclose the smoke-boxes so as to keep the stokeholds cool. The first ships in the navy to which this system was applied were the Conqueror and the Satellite. In the former 8 indicator horse-power per square foot of fire-grate, by natural draught, was augmented to 16.46 horse-power by forced draught; and in the latter the horse-power was increased from 10.15 to 16.9 horse-power, with an air pressure in the stokehold of from 1¼ inches to 2 inches of water. Mr. Richard Sennett gives the comparative results of more recent trials, summarized in the following table:[1]—

Table No. 187.—OPEN STOKEHOLDS VERSUS FORCED DRAUGHT (MR. SENNETT).

SHIP.	Year.	Load on the Safety-valve.	Indicator Horse-power.	Weight of Boilers.	Area of Fire-grate.	Indicator Horse-power per	
						Ton of Boiler.	Square Foot of Grate.
Open stokeholds.		lbs.	I.H.P.	tons.	sq. ft.	I.H.P.	I.H.P.
Inflexible	1878	60	8,484	756	829	11.22	10.21
Colossus	1883	64	7,492	594	645	12.61	11.62
Phaeton	1884	90	5,588	462	546	12.10	10.23
Forced draught.							
Howe	1885	90	11,725	632	756	18.5	15.54
Rodney	1885	90	9,544	474	567	20.1	16.83
Mersey	1885	110	6,628	306	399	21.7	16.61
Scout	1885	120	3,370	174	207	19.3	16.28

NOTE TO TABLE.—The given weight of boilers includes weight of water, funnel, uptakes, fittings, spare gear, &c.

Comparing averages, it appears that with open stokeholds and natural draught *versus* closed stokeholds and forced draughts, the indicator power is increased from 10.69 to 16.31 per square foot of fire-grate, or 52½ per cent; and from 11.98 to 19.90, or 65 per cent, per ton of boiler.

Examples of closed stokeholds are given in Plate XVIII. and fig. 979, page 690.

The system of forced draught opens the way for increase of efficiency, in facilitating the adoption of grates of diminished area in combination with acceleration of combustion. The reasons for such a conclusion have already been amply discussed in volume i.

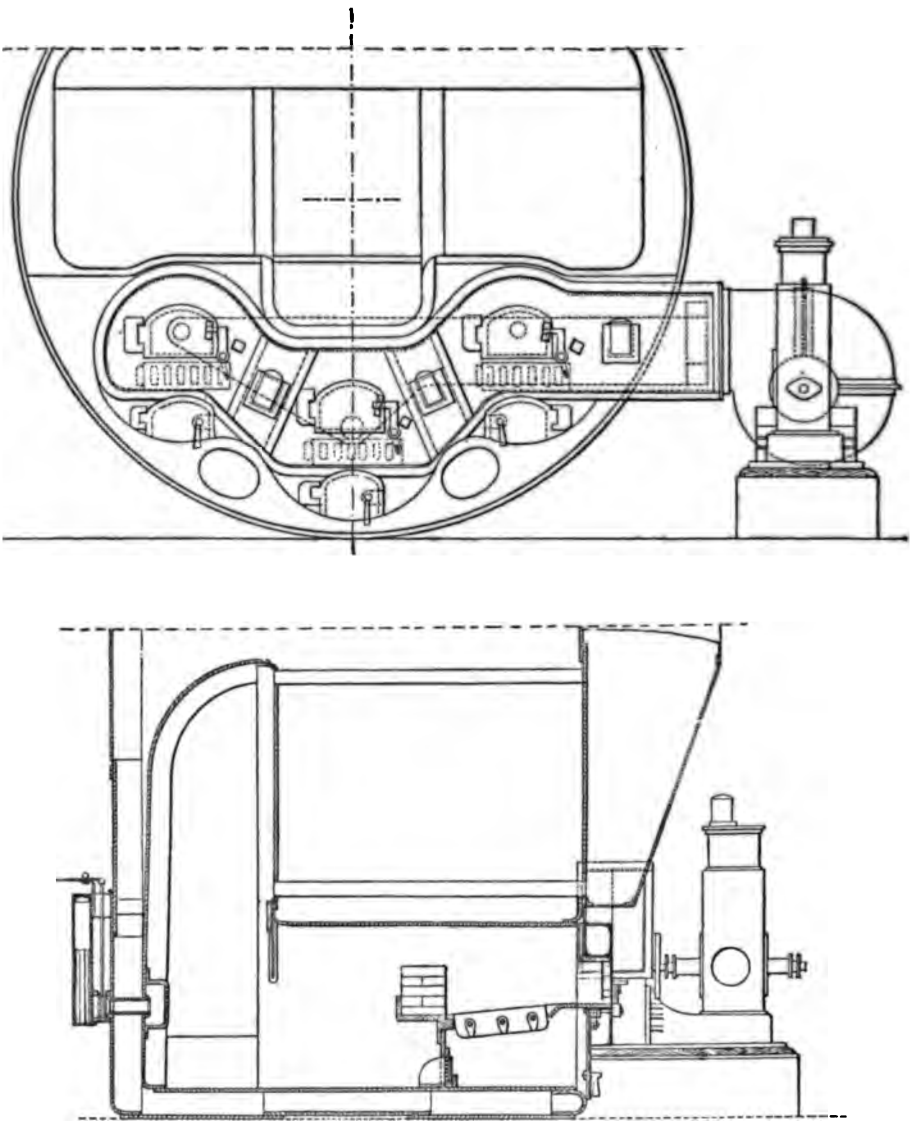
FORCED DRAUGHT WITH CLOSED ASH-PITS.

Forced draught in connection with closed ash-pits has been applied with good results by Mr. J. R. Fothergill, West Hartlepool, to the boilers of fifteen cargo steamers of from 1000 tons to 4500 tons, in the Mediterranean and Indian trades; five of which, having compound engines, and ten having triple-expansion engines, are fitted with his system of forced draught. The system is shown in figs. 968.[2] A casing connected with a

[1] See Mr. Sennett's paper on "Closed Stokeholds," read before the *Institution of Naval Architects* in 1886.

[2] See Mr. Fothergill's paper on "Forced Draughts," in the *Transactions of the Institution of Naval Architects*, vol. xxix. 1888.

forcing fan extends across the front of the boiler. The air forced into this casing passes into the ash-pits through gridiron valves in the back plate of the casing, just under the line of fire-bars. These valves are actuated



Figs. 968.—Fothergill's Forced Draught for Marine Boilers. Scale 1/48th.

by the latches of the furnace-doors. When the latch is pulled or knocked back against the stop, the lever on the latch spindle causes the valve to close; so shutting off the supply of air to the furnace before the door is opened, and preventing the hot gases and flames from being forced outwards when the door is opened the door is shut, and the latch is

pulled over to fasten it, the valve is at the same time opened. The door is of the ordinary type. A branch air-conduit is carried round to the back of the boiler, where it joins a casing from which a supply of air is passed through a stay-tube into a cast-iron perforated box fixed on the back wall of the combustion-chamber, facing each furnace. The supply of air to this box, which is regulated by means of a special valve, is delivered in streams to meet and mingle with the combustible gases from the grate; and that the mingling action may be the more effectual, a diaphragm or screen, cut out of scrap ship plates, is fixed like an inverted bridge at the end of each furnace-tube, beyond the ordinary bridge, by which the combustible current is deflected towards the air box at the back. The diaphragms last from six weeks to two months. The air leaves the fan at a pressure of from 3 inches to 3½ inches water-gauge. The principal supply of air passes to the ash-pits, where the pressure is from .50 inch to .70 inch water-gauge.

An important and, it may be said, an essential feature of the furnace is the comparative shortness of the fire-grates, which have been reduced by from 30 per cent to 50 per cent on the original lengths as adapted for natural draught. Correspondingly, the rate of consumption of fuel per square foot of grate has been augmented to from 20 pounds to 25 pounds per hour:—leading to augmented evaporative efficiency in accordance with the principles of radiation and absorption of heat, already fully investigated in vol. i. page 310, &c.

Table No. 188 gives particulars of the alterations of fire-grate made on the Marmora, Dania, and Etna, adapted for forced draught—the Marmora using inferior coal, the Dania using good coal, and the Etna being designed for high speed.

Table No. 188.—Particulars of Steamers fitted for Forced Draught (J. R. Fothergill).

Steamers.	Length of Fire-bars: Natural Draught.	Length of Fire-bars: Forced Draught	Reduction in Length of Fire-bars.	Grate-area in Sq. Feet: Natural Draught.	Grate-area in Sq. Feet: Forced Draught.	Percentage of Reduction in Grate-area.	Consumption per sq. ft. of Grate: Natural Draught.	Consumption per sq. ft. of Grate: Forced Draught.	Consumption per I.H.P.: Natural Draught.	Consumption per I.H.P.: Forced Draught.
	ft. in.	ft. in.	ft. in.							
Marmora...	4 3	3 0	1 3	52.416	37.00	29.41	15.52	21.41	2.05	2.00
Dania	5 0½	2 9	2 3½	51.678	28.188	45.45	17.77	25.36	2.12	1.73
Etna	5 0½	2 6	2 6½	52.937	26.25	50.41	12.94	25.10	1.60	1.35

Notes to Table.—Marmora: Arrangement to burn small coal.
Dania and Etna: To burn good coal, screened.
Dania: Mean funnel temperature, Fahr. 600° to 700°.
Etna: do. do. do. 700° to 800°.
Dania: Funnel damper ½ closed. } This depends on fit of damper to funnel.
Etna: do. ⅝ do. }
Water-gauge ash-pit air pressure ½ inch to ¾ inch.

Summary results of the comparative performances of the three steamers above named are given in table No. 189. The speeds have been calculated in terms of the number of days steaming and the distance,

taken over the whole period. The forced-draught voyages of the Dania, section (2) of the table, were made during the winter months, and the loss of speed was due to this cause. In section (3) of the table, the voyages are taken during the same months—September to February—for both draughts; and it is shown that, whilst the speeds are practically the same, there is a saving of 1.97 tons of coal, or 20 per cent per day steaming, and 13 per cent of the consumption for all purposes per day steaming. On the Etna, section (4), the economy of fuel effected by tripling the engines was 28 per cent, compared with the previous work of compound engines. By section (5) it is shown that in working triple-compound engines there was a gain of ¾ knot in speed, and a saving of 4.3 per cent of the total consumption of coal. The Marmora started from the Tees on her first voyage with forced draught on October 3, 1884.

Table No. 189.—Forced Draught versus Natural Draught (J. R. Fothergill).

Conditions.	Days Steaming.	Average Speed in Knots per Hour.	Consumption per Day Steaming.	Consumption for all Purposes per Day Steaming.
(1) S.S. Marmora:	days.	knots.	tons.	tons.
Natural draught, 12 voyages	16.81	7.74	8.72	10.52
Forced do. 11 „	16.69	7.48	8.49	9.79
Differences	—	−.26	.23	.73
(2) S.S. Dania:				
Natural draught, 13 voyages	16.31	7.91	9.84	10.96
Forced do. 8 „	15.89	7.44	7.66	9.37
Differences	—	−.47	2.18	1.59
(3) S.S. Dania (second comparison):				
Natural draught, 4 voyages	17.00	7.50	9.73	10.70
Forced do. 4 „	16.21	7.58	7.76	9.31
Differences	—	+.08	1.97	1.39
(4) S.S. Etna:				
Natural draught, 10 voyages........	21.95	7.83	10.57	11.58
Do. tripled, 3 „	27.72	7.58	7.36	8.33
Differences	—	−.25	3.21	3.25
(5) S.S. Etna (second comparison):				
Natural draught tripled, 3 voyages	27.72	7.58	7.36	8.33
Forced do. 6 voyages	23.32	8.38	7.06	7.97
Differences	—	+.80	.30	.36

The Falka is a new steamer, engined for triple expansion, brought out (1890) by Mr. Fothergill. Length between perpendiculars, 260 feet; beam, extreme, 36½ feet; moulded depth, 19 feet 5 inches; dead-weight capacity, 2480 tons; mean draught, 18 feet 1 inch; block coefficient, .75. The cylinders are 19 inches, 30½ inches, and 51 inches in diameter, with a stroke of 3 feet; in the capacity-ratios of 1, 2.58, and 7.22. The working pressure is 160 lbs. per square inch; making 553 indicator horse-power, at

64 revolutions per minute. The average rate of consumption of best Newcastle coals is 8 tons per day steaming, or 1.38 pounds per horse-power per hour, or 22 pounds per square foot of fire-grate per hour. The damper in the funnel is two-thirds closed; the pressure in the ash-pit is ½ inch by water-gauge; and the temperature in the funnel, at about 25 feet above the uppermost row of tubes, is from 600° to 700° F.

These results of the performance of the Falka represent Mr. Fothergill's average practice. The usual practice on the north-east coast, under natural draught, is to design the fire-grate area for burning from 14 to 15 pounds of fuel per square foot per hour. Mr. Fothergill increases the rate by 50 per cent, with a water-gauge of from ½ to ¾ inch in the ash-pit, which he does not intend to exceed; his object being to effect economy of fuel, not to increase the quantity of water evaporated per hour. The average air-supply is at the rate of 18 pounds of air per pound of coal. It is maintained that with the exercise of care and intelligence on the part of the stoker, no smoke is visible in burning fairly good Newcastle coal. But the modern fireman prefers to fill the furnace by a barrow load at a time, and to rest himself for 20 minutes before stoking again. In the face of such resistance, Mr. Fothergill has designed a system for using petroleum as an auxiliary fuel. This oil, passed from a close reservoir in an elevated position through a coil in the funnel, is gasified by the heat of the burnt gases, and under its own pressure is carried into the combustion-chamber, with air under pressure, through the tubes in the back of the boiler. By the intense heat of combustion of the petroleum, as the vapour mixes with the early combustible gases discharged immediately after a charge of coal, and thrown downwards by the deflector, the general temperature is raised and combustion is, it is designed, completed in the combustion-chamber.

FORCED DRAUGHT BY COMPRESSED AIR INTO THE ASH-PIT.[1]

A small steam launch was constructed in 1887 at the Mare Island Navy Yard, for service in Alaskan waters. The engine is compound, having cylinders 4 inches and 7 inches in diameter, with a stroke of 6 inches. The boiler is of the "low cylindrical" or direct horizontal tubular type, having 2.30 square feet of grate-area. To furnish the necessary draught, a system of forced draught was designed by Mr. Klotz, according to which a small air-compressor having a 4-inch cylinder—of the same diameter as the first cylinder of the engine—having a composition valve-seat screwed on to each end, with a hard india-rubber valve; the piston being driven from the first crosshead. The compressed air was conducted in an iron pipe to the front of the ash-pan of the boiler, where it was delivered through a rectangular slot in the pipe into an elongated nozzle forming part of the ash-pan door; the pressure being regulated by means of a wedge valve, by which the degree of opening of the slot could be varied. By the results of several trials it was shown that with a pressure

[1] See a paper on the subject by Mr. G. F. Kutz in the *Journal of the American Society of Naval Engineers*, 1889; page 330.

of air of from 1½ lbs. to 2 lbs. per square inch, the consumption of good bituminous coal was about 30 lbs. per square foot of fire-grate per hour.

The draught on this system is largely an induced draught. In the present case the quantity of compressed air delivered was not more than 10 per cent of the air chemically required for complete combustion; the remaining 90 per cent having been supplied by induction.

The system was tried on the steam launch of the Iroquois, 28 feet 2½ inches long. The boiler was like that already noticed. The shell was 41 inches in diameter, 36½ inches long; the furnace-tube was 23½ inches in diameter, with a fire-grate 17 inches long. There were 161 flue-tubes, 1½ inches in diameter outside, 18 inches long. The grate-area was 2.78 square feet, and there was 90 square feet of heating surface. The smoke-pipe was 8 inches in diameter, 6 feet high above the level of the grate. The compressing cylinder, 4⅛ inches in diameter, with 6 inches of stroke, was driven from the crosshead of the first cylinder. The opening for admission of air to the ash-pit was 1⅛ inches by 11 inches wide. The results of comparative trials with the natural draught and induced draught, using anthracite, were as follows:—

	Natural Draught.	Induced Draught.
Duration of trial, hours	2	2
Steam pressure in the boiler, pounds per sq. inch	50	60
Vacuum in condenser, inches	24	24
Revolutions of engine per minute	165.1	288.5
Temperature of feed-water	78°	93°
Temperature of water overboard	64°	67°
Coal consumed per hour, pounds	15	35
Water evaporated per hour	88.8	275.5

It is stated that, with natural draught, the speed was barely three knots per hour; whilst with the air-blast six knots were made easily.

It is stated that the induced draught system has been applied to the Cunard steamship Servia, as patented by Mr. Anderson, of Glasgow. He does not employ ash-pit doors. The jet and induction nozzles have the form of hollow truncated cones, and are on the pipe which conveys the compressed air. The greater part of the induced current enters the hollow cones. On the Servia the air compressors are driven by special compound engines, with an accumulator.

INDUCED DRAUGHT BY AN EXHAUSTING FAN.

Mr. W. A. Martin has for some years experimentally investigated the application of induced draught to marine boilers. He places a pair of exhausting fans, fig. 969, in the base of the funnel, one at each side of the uptake, mounted on a horizontal shaft which traverses the uptake, and is encased. The shaft is not continuous, but is made with two hollow couplings next the bearings, by means of which continuity of temperature is broken. The bearings work coolly. Either natural draught or induced draught can be employed, by setting open or closed a damper which is

fitted in the uptake. When the damper is closed, the burnt gases are

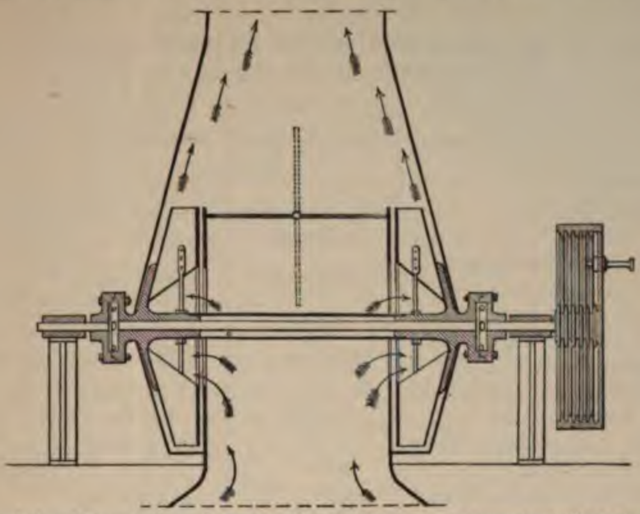


Fig. 969.—Induced Draught by an Exhausting Fan, showing ordinary draught cut off by valve damper.

seized and discharged by the fans into the funnel. The fans are driven by means of internal friction gear, and appear to work satisfactorily.

The experimental boiler, fig. 970, is cylindrical; 5½ feet in diameter, 6 feet long, having one furnace tube 2¼ feet in diameter, and 44 flue-tubes, 2¾ inches in diameter, 4½ feet long. The fire-grate has 6.75 square feet of area. The total heating surface is 152 square feet, or 23 times the grate-area.

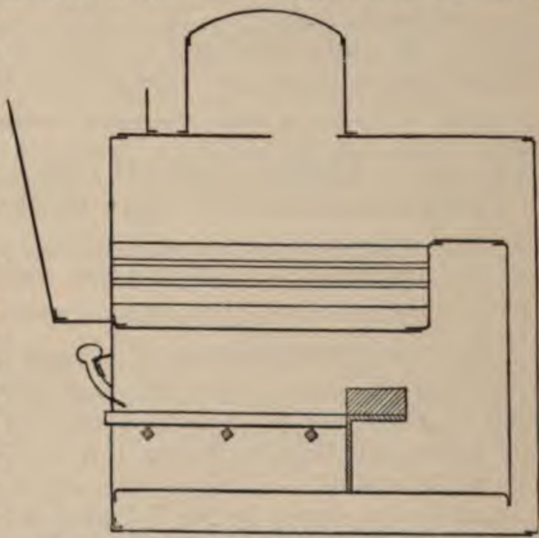


Fig. 970.—Experimental Marine Boiler for Induced Draught. Scale 1/32d.

Comparative results of performance of this boiler, by natural draught and forced draught, are given in the second and third columns of table No. 190. It appears that, with induced draught, nearly three times as much water was evaporated per hour as by natural draught, whilst the rate of evaporation per pound of coal was only about 6 per cent less: forming a very favourable contrast. Mr. Martin believes that the combustion is better with induced draught, and that for this object the relatively larger quantity and excess of air supplied per pound of coal by induced draught is on the whole beneficial. The last column of the table gives results of a trial of

Mr. Martin's system on a boiler taken out of the Polyphemus, at Portsmouth dockyard.

Table No. 190.—INDUCED DRAUGHT (MARTIN'S SYSTEM) VERSUS NATURAL DRAUGHT.

CONDITIONS	Natural Draughts.	Induced Draught.	Induced Draught (Boiler *ex* Polyphemus).
Date of trial	Aug. 24, 1889.	Nov. 27, 1889.	April 10, 1890.
Duration of trial	4 hours.	4 hours.	—
Coal consumed (Nixon's navigation)	367 lbs.	1080 lbs.	802
Do. do. per hour	92 "	270 "	—
Do. do. do. per square foot of grate	13.6 "	39.5 "	40.5 lbs.
Ash, per cent of coal consumed	—	2.8 per cent.	—
Pressure of steam	75 lbs.	75 lbs.	75 lbs.
Speed of fan, in turns per minute	—	1537 turns.	—
Vacuum in smoke-box	—	—	1½ ins. of water.
Air supplied per pound of coal	214 cu. ft.	343 cu. ft.	—
Temperature of feed-water	70° F.	53° F.	50° F.
Water evaporated	3208 lbs.	9061 lbs.	7902.5 lbs.
Do. do. per hour	802 "	2265 "	—
Do. do. do. per sq. foot of grate	13.6 "	39.5 "	399 lbs.
Do. do. do. do. foot of heating surface	5.27 "	14.9 "	8.9 "
Do. do. per pound of coal	8.93 "	8.4 "	9.84 "

CHAPTER LXXXVII.—DUPLICATE TRIPLE-COMPOUND OR TRIPLE-EXPANSION TWIN-SCREW MARINE ENGINES.

DESIGNED AND CONSTRUCTED BY MESSRS. JAMES & GEORGE THOMSON, CLYDEBANK, GLASGOW, FOR THE STEAM-SHIP CITY OF PARIS.

(Cylinders 45 inches, 71 inches, and 113 inches in diameter; stroke 5 feet.)

The City of Paris, the latest of the ships of the Inman and International Steamship Company, is 565 feet long over all, 63¼ feet broad, 42 feet deep, moulded; and of 10,500 gross tons. The ship, as well as her engines and boilers, was built by Messrs. J. & G. Thomson. She is propelled by two triple-expansion or triple-compound steam engines, of the inverted vertical type, designed by Mr. J. Parker, driving twin screws, one by each engine independently of each other. The adoption of twin screws was considered advisable, having regard to the enormous power requisite—20,000 indicator horse-power—and to ensure the safety of the ship by the duplication of parts. The two engines are placed side by side, separated by a longitudinal bulkhead; means of communication between the two rooms being provided by a water-tight door in the bulkhead.

Many of the features which are common to the engines of war-ships

have been introduced into the design of these engines, partly in order to minimize weight, and partly in consideration of the high speed adopted. The engines are built upon a very solid substratum in the ship, with, in addition, a cast-steel bed-plate—in three pieces, weighing about 16 tons each. The columns are of steel, and of the "split" type. The condensers, which usually form part of the main-engine structure, are made, as in war-ships, of brass, and are independent.

The cylinders are 45 inches, 71 inches, and 113 inches in diameter—or as 1, 2.49, and 6.31 in capacity—with a common stroke of 5 feet. The pressure in the boiler is 150 lbs. per square inch. The twin screws are 22 feet in diameter, with a pitch of 28 feet. The normal speed of the engines is 80 revolutions, or 800 feet of piston, per minute; and if the screws worked without slip, the speed of the vessel would equal 22 knots per hour. In one of her fastest homeward voyages, the City of Paris steamed the distance of 2894 knots from Sandy Hook to Roche's Point in 6 days 30 minutes, making an average speed of 20 knots per hour.

The cylinders and their covers are of cast iron, and are steam-jacketed. The pistons are of cast steel, of the dished or conical form. The piston-rods, connecting-rods, and other principal moving parts, are of ingot steel. The piston-rods are formed with tail rods, and they are fastened to the pistons with flange connections.

The crank-shafts, with the thrust, tunnel, and propeller shafting, are of Vickers' forged steel. The crank-shaft is built; the journals are 20¼ inches in diameter; the pins are 21 inches; the tunnel shafting is 19¼ inches, and the propeller shafting is 20¼ inches. The crank-shaft is hollow, 3½ inches in diameter internally. The pin also is hollow, 5 inches in diameter internally. The screw shafting is solid except the length outside the ship forward of the short piece of propeller shaft, which is 21 inches in diameter and 8 inches internally.

The valves are piston-valves, of which there is one for the first cylinder of each engine, two for the second, and four for the third cylinder: four valves being required for the large port-area in the third cylinder, and to obviate the strains due to the great overhang which would be caused by the employment of two valves only. The valves are worked by means of the ordinary expansion link-motion, and Brown's hydraulic reversing gear. The eccentric straps are of cast steel, lined with white metal. The equilibrium valve by which the supply of steam is controlled can be connected to the Dunlop governor, which will be described.

The steam-jackets of the cylinders are trapped to collect the condensation-water from them. The drain-pipes discharge into one main pipe which delivers the water into the condensers.

The surface-condensers are cylindrical, and are laid horizontally. The air-pumps are the only auxiliaries that are driven by the main engines. There are two air-pumps for each engine, 36 inches in diameter with a stroke of 25 inches, single-acting, placed vertical, and driven by back-levers from the piston-rod crossheads of the first and third cylinders.

The steam boilers are of steel, cylindrical, double-ended, nine in number, placed in three water-tight compartments, three in each compartment; 15½ feet in diameter, 19 feet long. The shell-plates are 19/32 inches thick. There are six furnaces in each boiler, of corrugated plate; of which the mean diameter is 3 feet 11 inches. The flue-tubes are 2⅜ inches in diameter, 7½ feet in length; 1056 in number in each boiler. The total heating surface is 50,040 square feet. The furnaces at each end have a combustion-chamber in the middle common to both ends. The weight of each boiler, empty, is 74 tons. The boilers are worked on the closed-stokehold system of forced draught. At each side of the upper deck there are erected six large rectangular plate-iron hatchways, fitted with shield lids on the tops, raised or lowered by means of screw gear. These twelve shafts reach down to the fire-rooms, and at the bottom of each a 5½-feet fan is at work; the twelve fans being driven by twelve different steam engines. Driven at a speed of 500 turns per minute, these fans draw down and deliver air into the stokeholds, under ½-inch water-gauge pressure.

The gross weight of the boilers and engines, including the water in the boilers and condensers, is 2600 tons.

As a maximum performance, when the engines made 89 revolutions, or 870 feet of piston per minute, 20,600 indicator horse-power was exerted, with a consumption of 1.67 pounds of coal per indicator horse-power per hour.

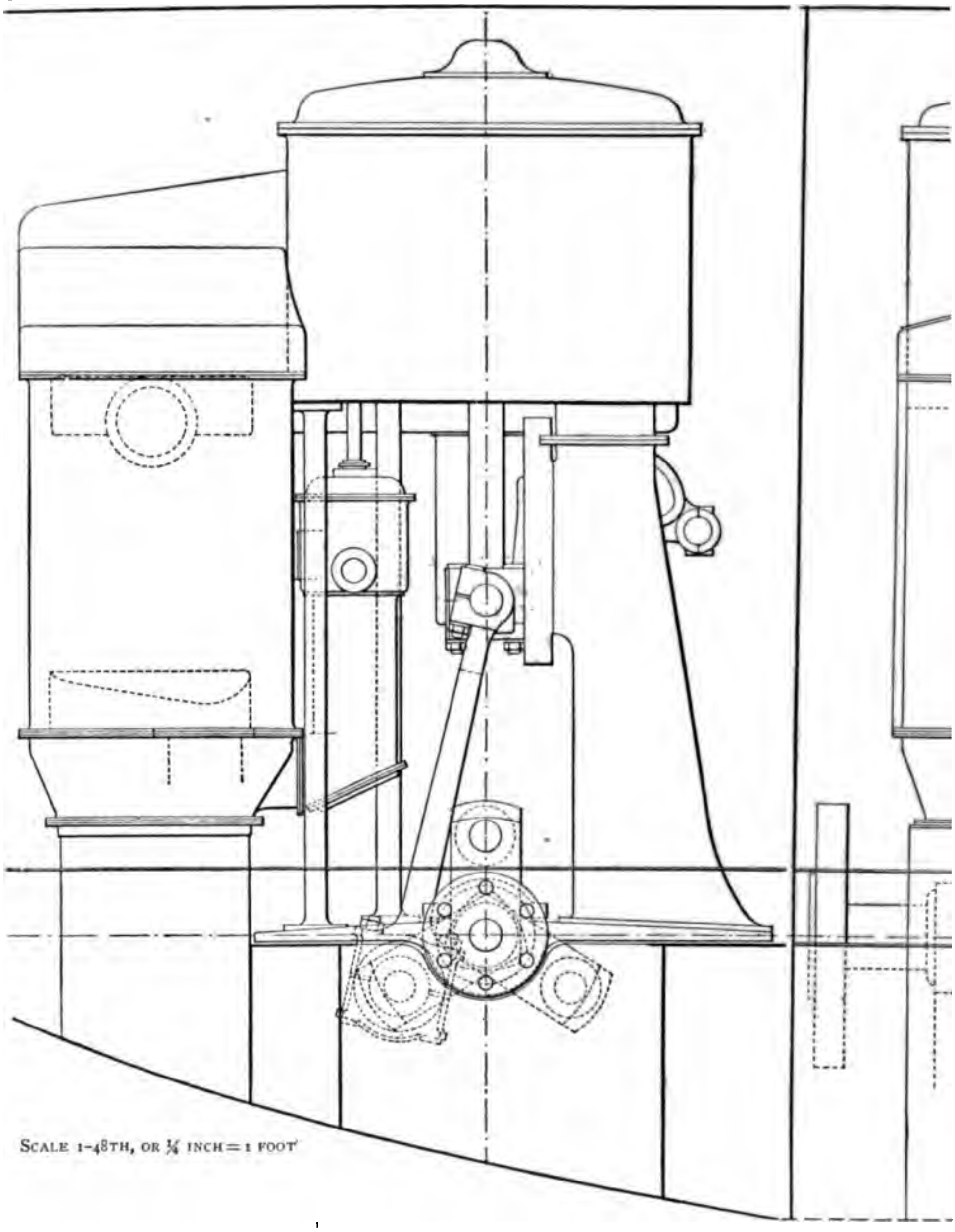
AUXILIARY MACHINERY.

The hydraulic installation of the City of Paris is stated to be the most extensive that has been fitted on shipboard. It is served by two pumping engines in the engine-room—compound surface-condensing—constructed by Messrs. Brown & Co. They work seven hoists, nine derricks, two warping ends, and two warping capstans aft on the promenade deck. The turning engines also are worked by hydraulic power: the ram actuating a pawl on the worm-shaft, the worm gearing into a worm-wheel on the engine-shaft.

The boilers are fed by four Worthington vertical pumps, two in each engine-room, associated with Gilmour's feed-heaters. Each pump has two 12-inch steam cylinders and 28½-inch double-acting water-plungers, with a stroke of 10 inches. One of the pumps in each room supplies the feed-heater with water at the temperature of the hot-well. In the feed-heater the temperature is raised by the use of steam from the boiler to nearly the temperature in the boiler; and by the second pump the heated feed-water is delivered, at a slightly increased pressure, to the boilers. On this system of highly-heated feed-water, all impurities are deposited in the feed-heater, from which they are blown off from time to time. The heater is easily cleaned. Thus also is obviated any strain that might otherwise arise from irregular cooling of the plates of the boiler. The heater can be put out of action at any time, with only one pump in action; and as each pump has capacity sufficient for supplying all the feed required, the other pump may

FOR

Fig. 3.—END ELEVATION, AT 3RD CYLINDER.



Scale 1-48th, or ¼ inch = 1 foot

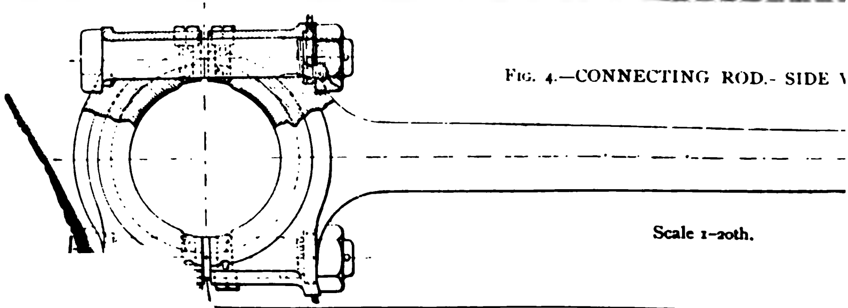


Fig. 4.—CONNECTING ROD.- SIDE \

Scale 1-20th.

be regarded as an alternative in case of a breakdown. The first pump, which delivers from the hot-well into the feed-heater, is controlled by a float in the tank; so that it is impossible that there can be either an overflow or an insufficient quantity in the hot-well.

There are two fire and bilge pumps in each engine-room for general purposes. They are available as feed-pumps if required; and they are connected to the double-bottom system of piping.

Circulating water is supplied to the main condensers by means of four 15-inch centrifugal pumps; two for each engine. Each pump is capable of supplying all the condensing water required.

An auxiliary condenser and pump is placed in the engine-room, for condensing the exhaust steam from the auxiliary engines.

A rudder of large area is provided, worked by hydraulic power, by means of which alone, when both engines are going at full speed, a complete circle can be turned in five minutes.

Chapter LXXXVIII.

PAIR OF VERTICAL TRIPLE-EXPANSION MARINE STEAM ENGINES FOR H.M.S. RENOWN, SANSPAREIL, AND TRAFALGAR.

DESIGNED AND CONSTRUCTED BY MESSRS. HUMPHREYS, TENNANT, & CO., LONDON.

PLATES XVII. AND XVIII.

(Cylinders 43 inches, 62 inches, and 96 inches in diameter; 4¼ feet stroke.)

The ships above named are ironclads, propelled each by two four-blade screws, 16½ feet in diameter, with two engines each of 6000 indicator horse-power, together 12,000 horse-power. The engines, Plate XVII. and figs. 971 to 973, have been designed to develop great indicator power on a light weight. Steam is supplied from eight boilers under forced draught. The three cylinders of each engine are overhead, and work vertically to the crank-shaft below, which is fastened to the screw-shaft. The cylinders with their valve-chests are ranged in line, fore and aft; and each crank works in two bearings, making together six bearings. The first, second, and third cylinders are respectively 43 inches, 62 inches, and 96 inches in diameter, with a common stroke of 4¼ feet. Their areas are as 1, 2.09, and 4.99. The axes of the first and second cylinders are 12½ feet apart, and those of the second and third cylinders are 11 feet apart; making together a distance of 23½ feet between the axes of the first and third cylinders. The tops of the cylinders are about 18 feet 4 inches above the level of the seatings for the sole plate of the engines.

The working pressure is 135 lbs. per square inch above the atmosphere. When 12,000 indicator horse-power is developed, the engines make 95 turns, or 808 feet of piston per minute.

The framing consists of vertical cast-iron columns in front, vertical

6½-inch wrought-iron columns on the wing side, and cast-steel bearing-frames or base-plates for the crank-shaft. These bearing-frames are formed with lateral flanges, by which they are bolted to the vertical cast-iron frames and to the wrought-iron columns. They are secured to the frames running fore and aft and athwart ship; built up of steel plates and angle-irons, and forming part of the structure of the ship. By this arrangement the whole of the framing becomes self-contained and rigid.

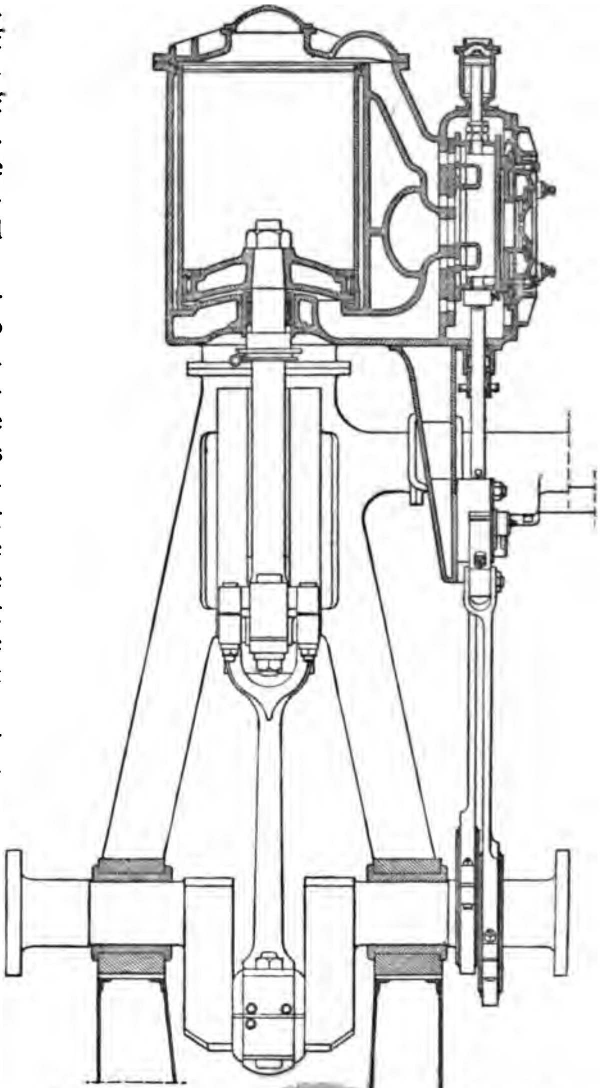


Fig. 971.—Hu— rs' Vertical Marine Engine: Section through the Cy— Scale 1/48th.

The cylinders are supported by and bolted to the vertical framing; and close under the attachments of the cylinders the vertical cast-iron columns are rigidly connected together by castings running fore and aft, which are utilized for carrying the brackets for the reversing shaft, and for securing the sector block-guides. At the wing sides the cylinders are bound together by a 4¾-inch wrought-iron bar, passed through brackets cast on the cylinders, and fastened to them with nuts. It serves also as a stay between the cylinders when the ship is used for ramming.

All the steam cylinders are of cast iron. They are thoroughly steam-jacketed, with the exception of the upper first and second covers. ... has a separate liner of Whitworth fluid-pressed steel, fla ... there with countersunk screws; secured ... r by an elastic metal ring, shown fol ... d to the liner and the ... to the ... ; for

inequality of expansion and contraction of the liners and the jackets. In the second and third cylinders the liner is jointed at the top with a stuffing-box. To correspond somewhat with the pressures and temperature of the steam in the cylinders, the pressure of the steam in the jacket of the first and second cylinders is 135 lbs. per square inch, the working pressure in the boiler; and in the third cylinder it is 50 lbs. per square inch.

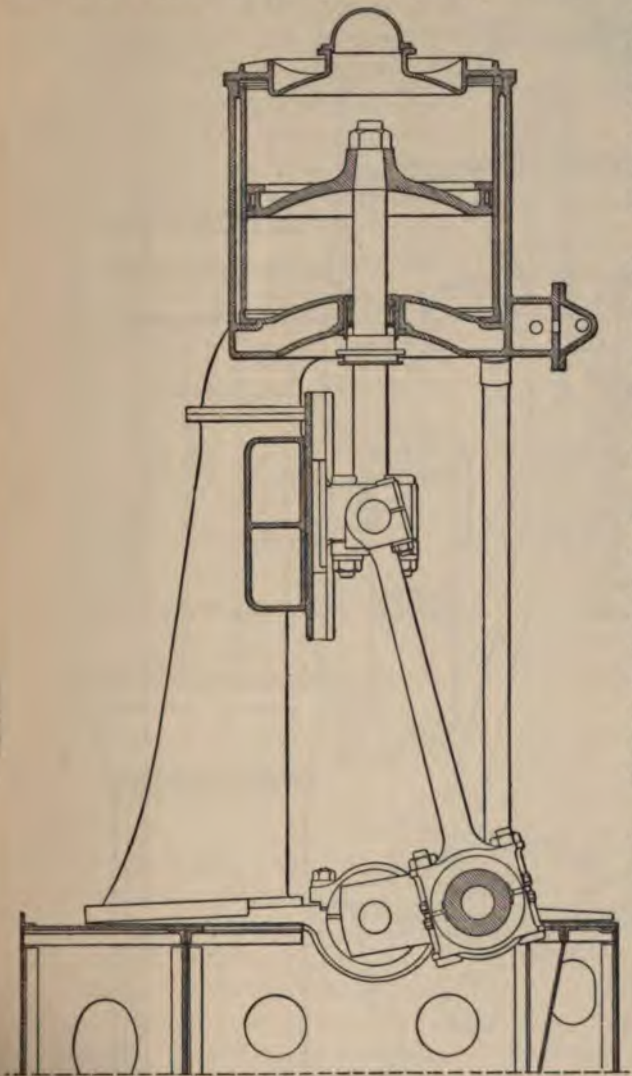


Fig. 972.—Humphreys' Vertical Marine Engine: Section through Second Cylinder. Scale 1/48th.

The liners of the first, second, and third cylinders are respectively 1¼ inches, 1¼ inches, and 1½ inches thick. The jackets are 1¾ inches, 1¾ inches, and 2½ inches thick.

The first and second cylinder-covers are of cast steel. The third cover is of 1½-inch cast iron. A doorway of ample size is formed in each cover for inspection: obviating the need for removing the whole cover.

The usual starting valves are fitted, one to each cylinder, with hand-gear to the double-seated equilibrium-valve for admitting steam to the first cylinder. The main steam pipe is of copper.

The ordinary double-ported slide-valve and link-motion are applied to each cylinder. The valves are of cast iron, working on cast-iron faces, cast separately n the cylinders, and secured in place by brass countersunk screws. The ure on the back of the valve, in the first and the second cylinders, is d by a cast-iron ring, which has a bearing on the back of the valve. ng is connected to the cover of the valve-chest by an elastic copper

ring, of a folded section, one edge being jointed to the ring and the other edge to the cover. It is kept in its place by spiral springs. This system of relief has been extensively practised by the constructors, and it works

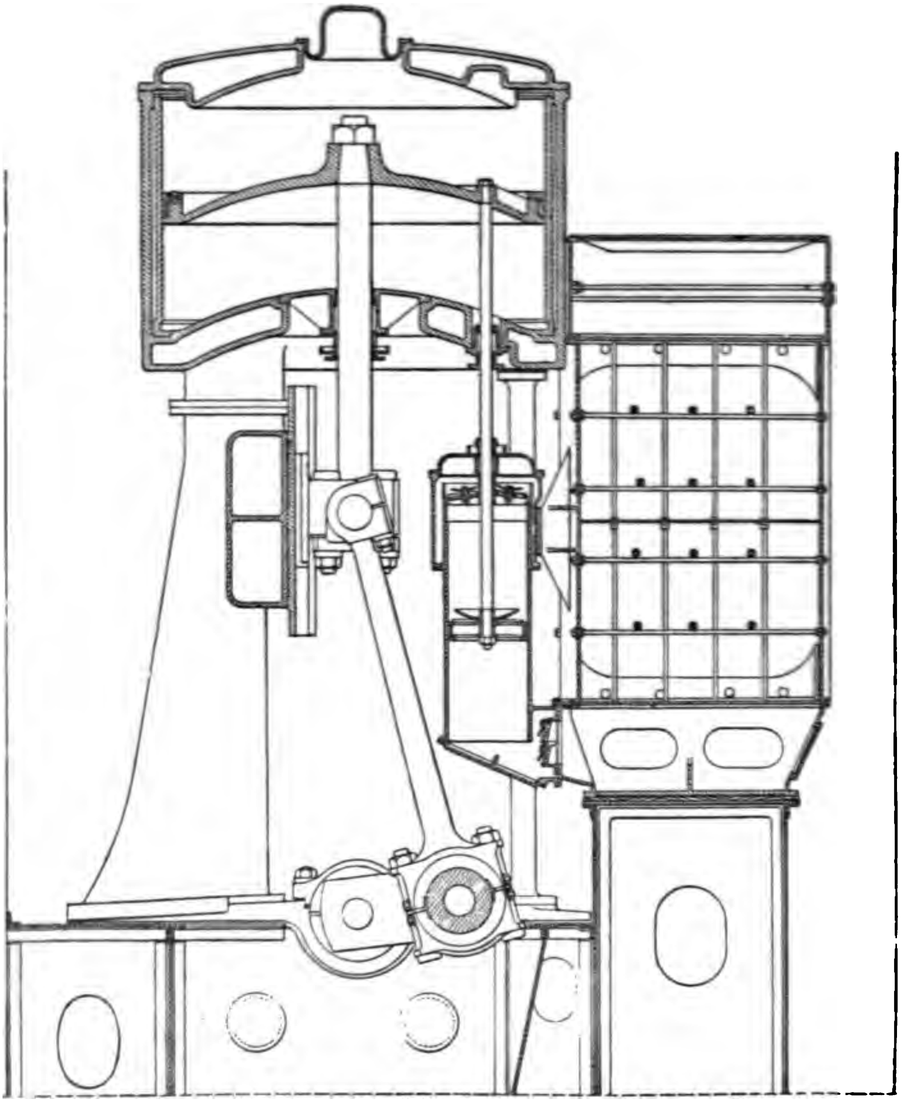


Fig. [illegible] – Humphreys' Vertical Marine Engine: Section through Third Cylinder and Condenser. Scale 1 48th.

very well. The weight of the slide is balanced by the steam pressure on a piston in a small balance-cylinder or he top of the valve-chest, thus relieving the link-gear of the weight o

A condenser, figs. 973 and 9 e, of ⅝-inch cast gun-metal plates, bolted toge amber, 8 feet 9 inches wide, 5 feet 5 inch feet 7 inches

high, outside dimensions. The four walls are each of one plate, flange-jointed, and joggled to its neighbours. The walls, also the top and bottom of the chambers, are stayed by 1⅛-inch tie-rods, transversely and vertically, with double-nuts at each end, pitched at 18 inches horizontally, and at from 12 inches to 16 inches vertically. It contains 4768 condensing tubes of solid-drawn brass, ¾ inch in diameter outside, .05 inch or $^1/_{20}$ inch in thickness, placed vertically, secured to the tube-plates with tape-packing and screwed glands. The tubes present a cooling surface of 7000 square feet. The steam is condensed within the tubes, the condensing water is circulated outside the tubes, and the water is directed with the aid of circulating plates. The water is driven through the tube-case by two centrifugal pumps in each engine-room, driven by separate single steam engines. Either pump can be used independently of the other. They draw from the sea and the bilge, and they can discharge either through the tube-case or directly overboard. The pump-fans are 3 feet 10 inches in diameter; the suction and discharge pipes 18 inches. The steam-cylinders are 13 inches in diameter, with a stroke of 12 inches.

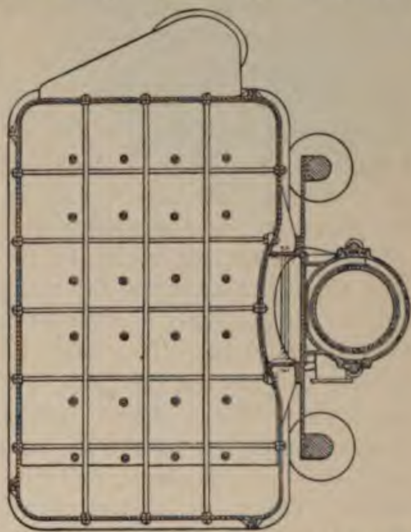


Fig. 974.—Humphreys, Tennant, & Co.'s Vertical Marine Engines: Horizontal Section of Condenser Scale 1/48th.

The steam from the third cylinder of the main engine is discharged into an ante-chamber, made of gun-metal plates, on the top of the condenser, 2 feet high, from which it passes into the condensing tubes. The condensed steam falls into a lower chamber, 21 inches high, of gun-metal plates, on which the condenser is supported. Thence the water passes into the bottom of the air-pump.

The air-pump is of brass, 1 inch thick, single-acting, 20 inches in diameter, vertical, the bucket of which is worked directly by a rod from the third piston, and therefore having the stroke of the engine, 4¼ feet. The bucket-valves, foot-valves, and discharge-valves are of india-rubber on grated seats. The water is discharged from the pump into a tank in the engine-room, from which the feed-water for the boilers is drawn by the feed-engines.

The air-pump is fastened by means of a wrought-iron plate to the frame columns and to the condenser. It is also stayed to the third cylinder by two stays, one at each side.

The first piston is of cast iron, 8 inches thick, hollow, of 1½-inch metal; formed slightly conical for stiffness. The second and third pistons are of cast steel, each a single web, a flat segment of a sphere, or conical in

section, 3 inches thick near the centre, tapered to 1½ inches at the rim. The rim of each of these pistons is 8 inches wide. Each piston is fitted with a junk-ring and metallic packing of the ordinary type, pressed outwards by steel springs.

The piston-rods are of steel, all of one diameter, 8½ inches. They are each let into and through the piston with a taper, and secured by a nut. The crosshead is forged solid on the rod, to which the pin is fastened with a cap and two bolts. The guide is bolted to the vertical cast-iron columns on one side. The guide-plate is of wrought iron shrunk on the head of the piston-rod, and secured with collar-screws.

The connecting-rods are of wrought steel, 8¼ feet in length, or 3.88 times the length of the cranks. The upper end of each rod is forked to take the gudgeon, which is of steel, 8½ inches in diameter, and 14 inches long in the fork. The fork-ends are forged solid on the rod, and are formed to grip the gudgeon, being each clamped on it by a 3-inch bolt and nuts. The gudgeon is thus rigidly held, and is easily removable. The lower end is of the cap-and-bolts construction. It gives a bearing 16¼ inches in diameter, 18 inches long. The brasses are lined with soft metal. They are circular, 1⅞ inches thick, and are secured by screws to the ends of the connecting-rod and its cap, to prevent its closing or gripping on the crank-pin. The cap-bolts are 4¼ inches in diameter. The body of the rod is 7¼ inches in diameter at the larger end, and is tapered to 6 inches at the smaller end. The piston-rod, it may be noted, is larger than the connecting-rod, as it is made large enough to provide the required strength for the screw end.

The crank-shaft for each engine is made of Whitworth steel, in three sections, interchangeable, connected by couplings forged on, each with six coupling-bolts and nuts. Each shaft is 16 inches in diameter. It is hollow, 8 inches in diameter inside. The pins are 16¼ inches in diameter, 18 inches long; hollow, 8 inches in diameter inside. The limbs of the cranks are 12 inches thick by 18 inches wide. Each crank is carried in two bearings, each 20 inches long, of brass, lined with soft metal. The lower part of each brass is circular, and so may be removed without lifting the shaft. There are no collars on the journals, and the fore-and-aft position of the crank-shaft is maintained by the thrust-blocks. The cranks are placed at angles of 120° with each other, equally placed round the circle. By such adjustment the cranks and the reciprocating parts are well in balance, and an equable stress is communicated through the shafting to the screw. The lubrication of each crank-pin is provided by means of a centrifugal lubricator fixed on one side of a crank-arm. The oil is dropped into the part of this lubricator nearest to the centre of the shaft, and is driven by centrifugal force into a hole in the crank-pin, from which it passes by two holes drilled in the crank-pin on [illegible] bearing.

Each link-motion for the v[illegible] two cast-iron eccentrics, having 10-inch throw, with wrou[illegible] feet [illegible] long between centres, fitted with br[illegible] tl[illegible] The link is a

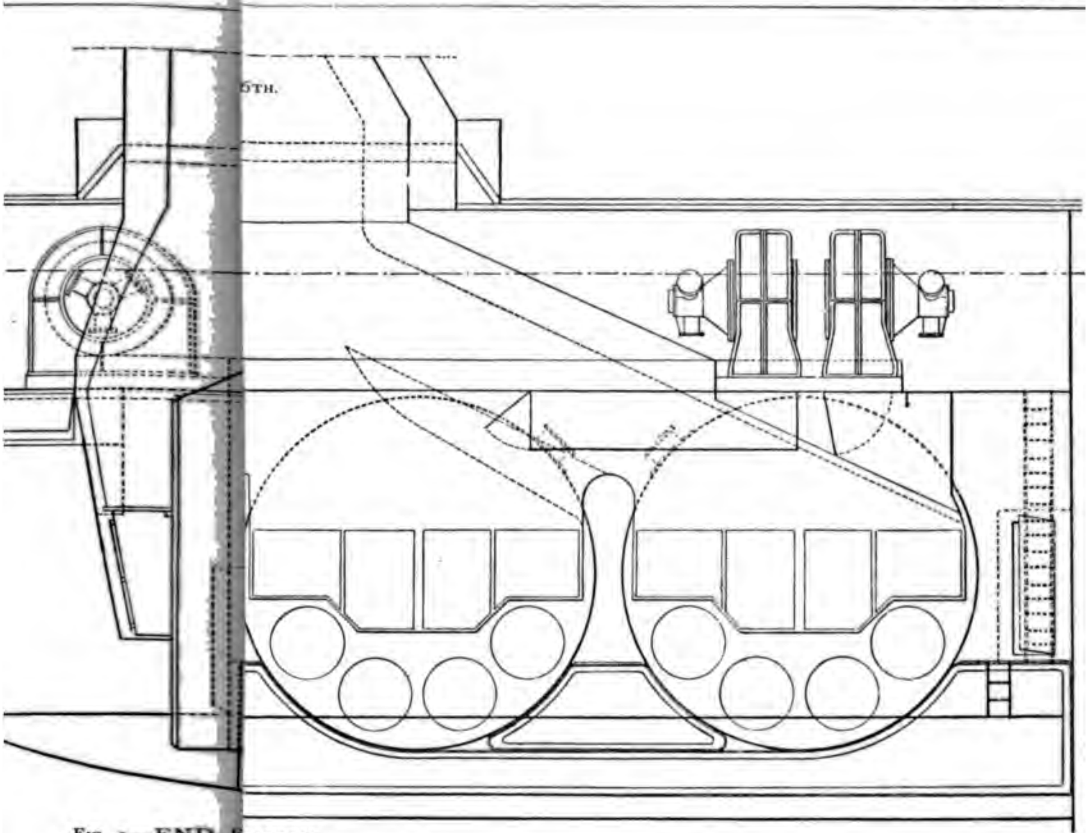
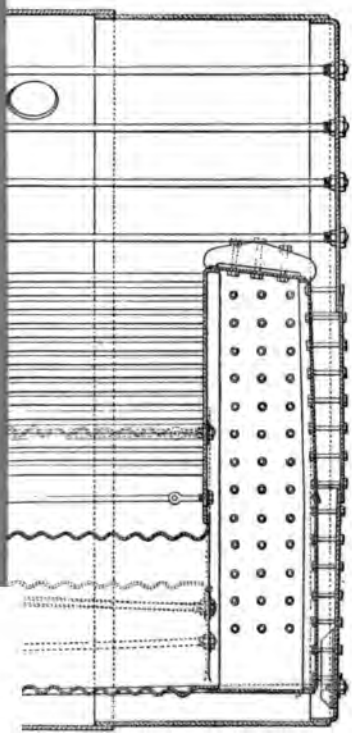


FIG. 2.—END E ATION.



Diameter of each Boiler, 15 ft. 2 in.
Length, 9 ft. 6 in.
Four Corrugated Furnace Tubes, 3 ft. 1 in. in diameter inside, 6 ft. 6½ in. long.
490 Flue-tubes, 2½ in. in diam., 6 ft. 8 in. long.
Chimney, 7 ft. 1 in. in diameter.
Working Pressure of Steam, 153 lbs. per square inch.

TUDINAL SECTION OF BOILER.

plain curved bar of steel, 5 inches square in section, 4 feet 4 inches long between the centres; having bearings of brass, all adjustable. The link of each cylinder may be set so as to vary the cut-off at will in any cylinder independently.

A small two-cylinder engine, fitted with automatic valve-gear, is provided for the purpose of reversing the main engines.

The feed-pumps and bilge-pumps are entirely separate from the main engines.

A small double-cylinder steam engine is fitted in each engine-room, for turning the main engines; having gear so arranged that the worm can be readily placed in or out of gear.

The steam boilers, Plate XVIII., eight in number, are divided into four groups, inclosed in four compartments formed by fore-and-aft and athwart-ship bulkheads. The boilers of each compartment are provided with two double-cylinder feed-engines.

When the boilers are worked with forced draught, the stokeholds are closed in by an air-tight screen fitted with hinged doors in front of the smoke-box doors, run up to the lower side of the debris deck. The air is forced into the stokeholds by 5-feet fans driven by Brotherhood's three-cylinder engines.

The boilers are of Siemens-Martin steel. They are cylindrical, 15 feet 2 inches in diameter, 9½ feet long outside; constructed for a working pressure of 135 lbs. per square inch above the atmosphere. One of these is illustrated in section by figs. 3 and 4, Plate XVIII. The ring-plates are $1\frac{5}{32}$ inches thick, two in number; the end-plates are flanged to go inside the ring-plates. The three ring seams are formed with 5 inches of lap, and double-riveted with ⅞-inch rivets, at 3½ inches of pitch: the centre-line of each row of rivets being 1⅜ inches from the edge of the plate. Each ring is made up of six plates bent to the circles, and united by double straps or welts, 16½ inches wide, one inside the joint, $^{13}/_{16}$ inch thick, and one outside, $^{15}/_{16}$ inch thick, triple-riveted with 1⅛-inch rivets, at a pitch of fully 4¾ inches longitudinally. The three rows of rivets are zigzag, and the centre-lines of the outer rows are 1½ inches from the edges of the plates and straps.

The end-plates are each in three pieces; the upper and lower, ⅞ inch thick, of which the lower is cut and flanged to take the furnace-tubes; and the middle piece, which, for the front, is the tube-plate $^{13}/_{16}$ inch thick, and for the back is ¾ inch thick. The pieces of each end are united with 4⅝ inches of lap, and are chain-riveted with two rows of ⅞-inch rivets, at 2¾ inches of pitch. The centre-lines of the rows are 1¼ inches from the edges of the lap.

There are four furnace-tubes in each boiler, of corrugated plate, $^{15}/_{32}$ inch in thickness, 3 feet 1 inch in diameter inside, 6 feet 6½ inches long. They are riveted to the front end-plate, and to the bottom plates and tube-plates of the combustion-chambers. There are two combustion-chambers, divided by a central vertical water-space, of ½-inch plates, except the tube-plates,

which are 13/16 inch thick. The water-spaces are stayed with 1¼-inch screwed steel stay-bolts, nutted at each end, pitched at 7 inches between centres. The chambers are 2 feet 1½ inches long at the top, widened slightly towards the bottom. The back water-spaces are 4 inches wide at the bottom, 6 inches at the top. The middle water-space is 5 inches wide, and the side spaces are 4½ inches.

The flue-tubes are of wrought iron, 2½ inches in diameter outside, 6 feet 8 inches long between the tube-plates, pitched at 3½ inches apart between centres. There are 245 tubes for each combustion-chamber and pair of furnace-tubes, or 490 tubes in all. These comprise 378 ordinary tubes, .165 inch or fully 5/32 inch in thickness; and 112 stay-tubes, ¼ inch thick. The ordinary tubes are riveted over the tube-plate of the combustion-chamber, and expanded in the tube-plate of the smoke-box. The stay-tubes are screwed into both tube-plates, and riveted over at the end in the combustion-chamber. The stay-tubes are generally 7 inches apart horizontally, and 10½ inches vertically, between centres.

The upper part of the ends of the boilers are stayed with four rows of 1 15/16-inch bolts, pitched 14 inches apart vertically, 14¼ inches horizontally. Stay-bolts are also placed about the furnace tubes. The roof of each combustion-chamber is stayed with ten stay-bars, and 1¼-inch bolts and nuts.

Six manholes are formed in the front plate about the furnace tubes, and one over the steam-space.

The fire-grates are 7 feet in length. The fire-bars are of cast iron, 1 inch thick, with ½-inch air-spaces. There are special cast-iron bars at each side to suit the corrugations. The total grate-area for one boiler is 86¼ square feet; and the total heating surface is 2500 square feet, or 29 times the grate-area.

There are two chimneys or funnels, of steel plates, for the eight boilers, in two groups of four boilers; 7 feet 1 inch in diameter, of 3/16-inch iron plate, and 65 feet in height above the level of the fire-grates.

CHAPTER LXXXIX.

PAIR OF HORIZONTAL TRIPLE-EXPANSION MARINE STEAM ENGINES FOR FAST TWIN-SCREW CRUISERS.

DESIGNED AND CONSTRUCTED BY MESSRS. HUMPHREYS, TENNANT, & CO., LONDON.

PLATE XIX.

(Cylinders 30 inches, 44 inches, and 68 inches in diameter; 3 feet stroke.)

These engines, Plate XIX. and figs. 975 to 978 annexed, are designed to indicate 6000 indicator horse-power, under forced draught, for ve screw cruisers, in which great power is required with The engines are side by side, reversely to each oth to the screw shafts. They are horizontal, and

plating and angle iron, built up from the hull. When developing 6000

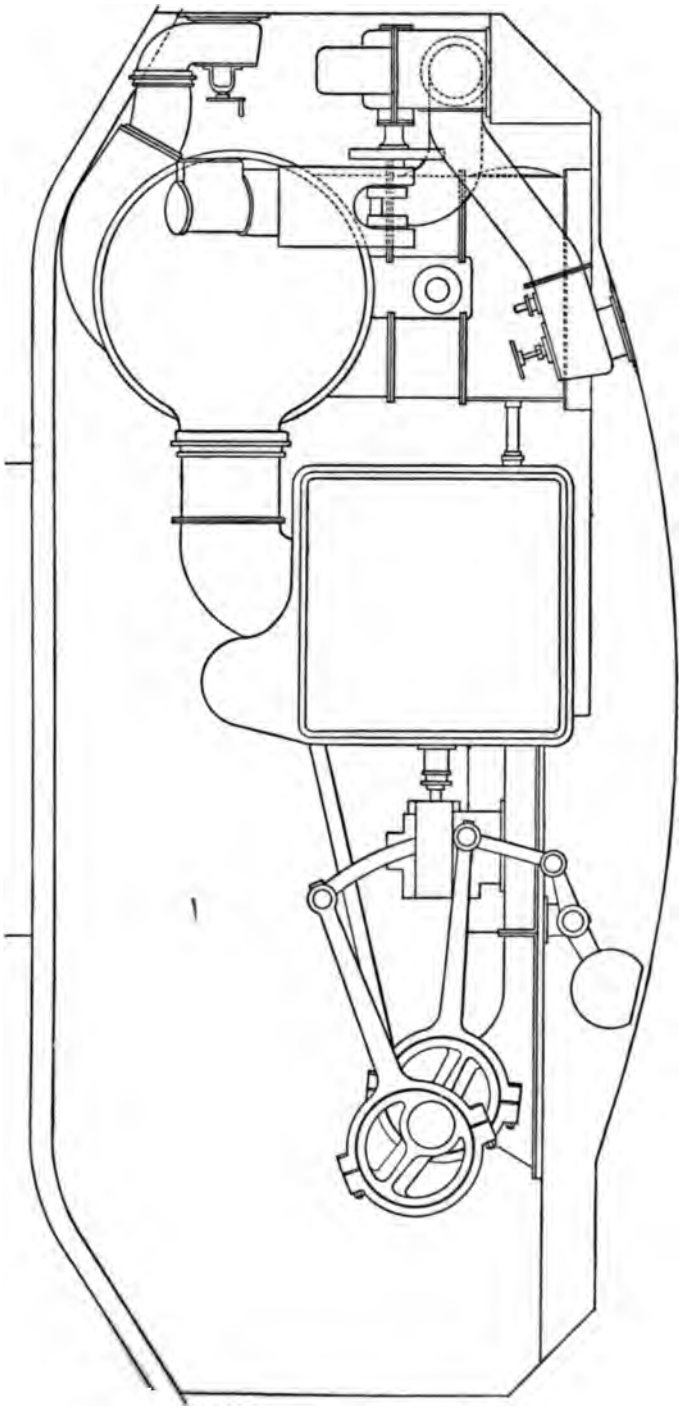


Fig. 975.- Horizontal Triple-expansion Marine Steam Engines; Humphreys, Tennant, & Co. Side Elevation. Scale 1/48th.

indicator horse-power the engines make 135 turns, or 810 feet of piston per minute.

The first, second, and third cylinders are respectively 30 inches, 44 inches

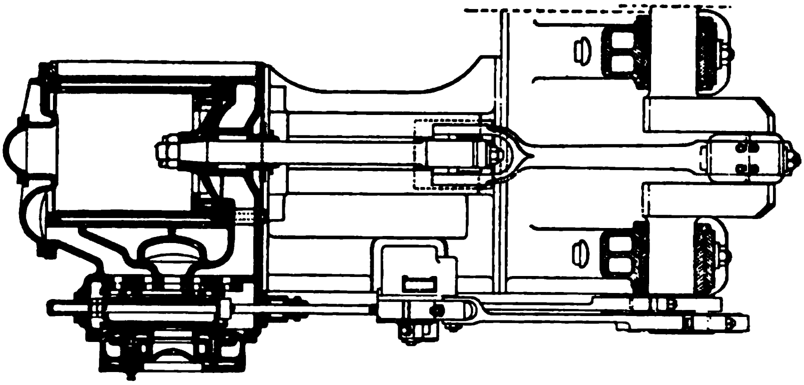


Fig. 976.—Humphreys' Horizontal Marine Engine: Horizontal Section through First Cylinder. Scale 1/48th.

and 68 inches in diameter, with a stroke of 3 feet. The areas are as 1, 2.15, 5.14. The screw-shafts are hollow, 11 inches in diameter outside, 6 inches inside; and they are 17½ feet apart transversely, each turning a three-

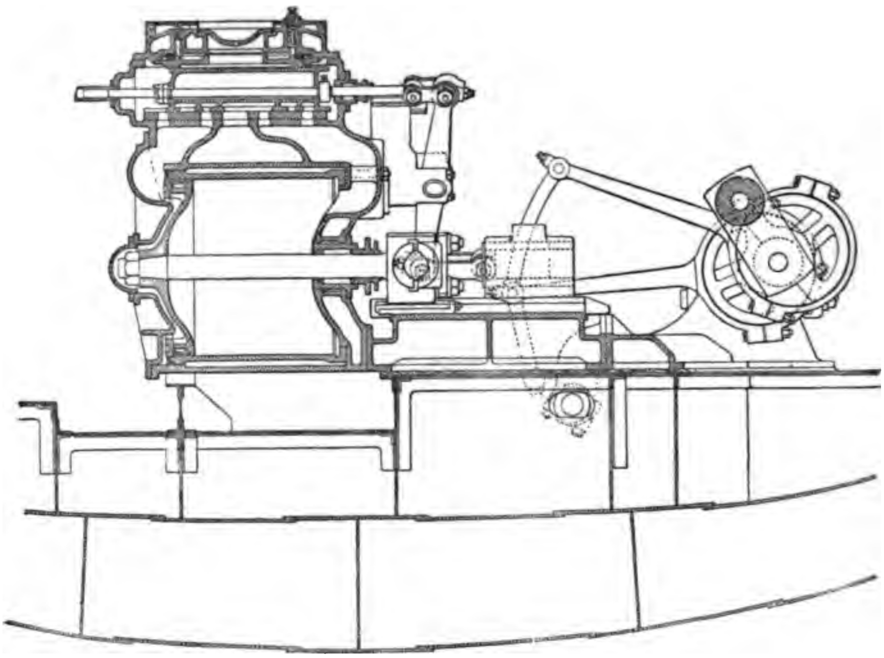


Fig. 977.—Humphreys' Horizontal Marine Engine: Vertical Section through Second Cylinder. Scale 1/48th.

blade screw 13 feet in diameter. The crossheads are supported on and
guided by cast-iron beds. -rods are each 6 inches in diameter.
The connecting-rods are four times the length of the cranks.

The cylinders are compactly arranged and bolted directly together, without the intervention of the valve-chests. For the first and third cylinders the valve-chests are placed at the outer sides of the cylinders; for the second cylinder the valve-chest is placed on the top of it. By this expedient the first and second cylinders are only 4 feet 4 inches apart, and the second

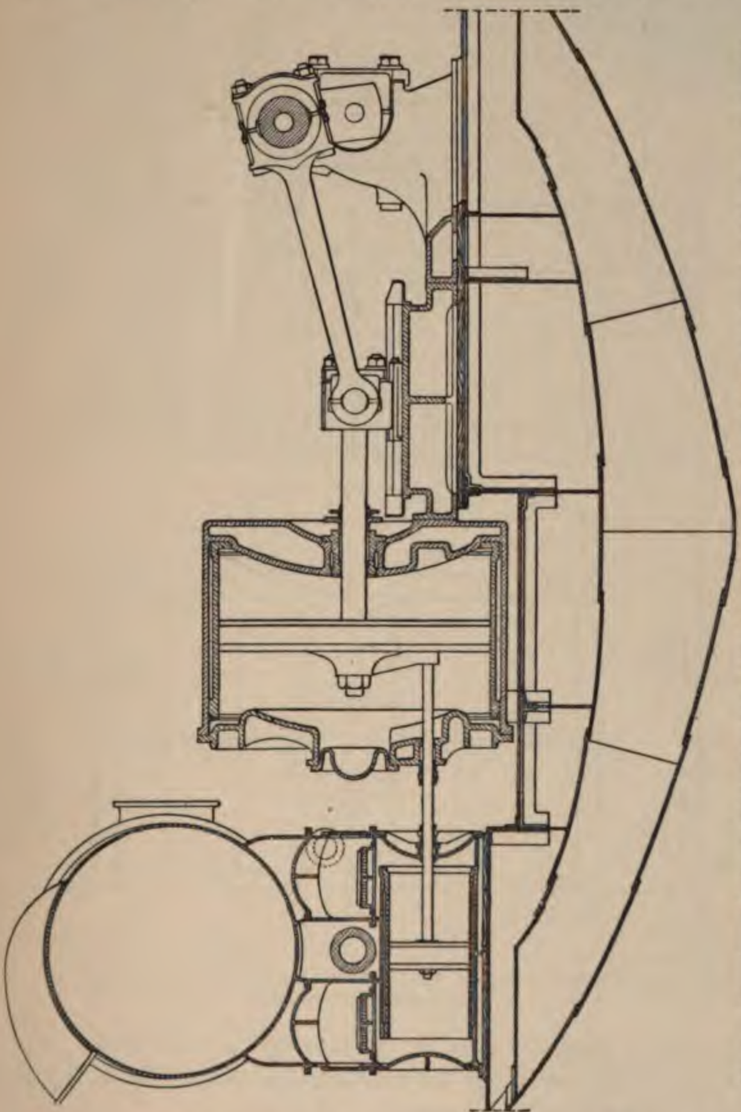
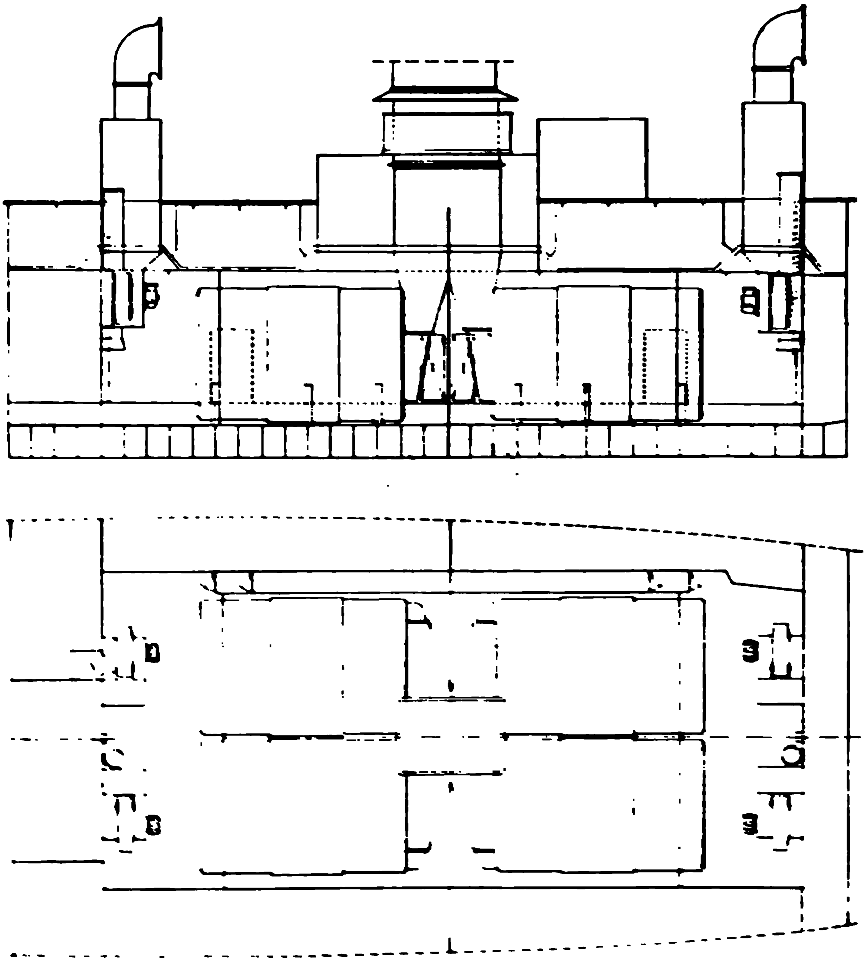


Fig. 978.—Humphreys' Horizontal Marine Engine: Vertical Section through the Third Cylinder, Condenser, and Air-pump. Scale 1/48th.

and third are 5½ feet apart, between their axes. The crank-shaft is 12 inches in diameter, and is carried in four bearings, which are 17 inches long for the first cylinder and 24 inches for the third cylinder. The crank-pins are 12½ inches in diameter, 12 inches long. They and the shaft are hollow, 5 inches in diameter inside.

The details of the cylinder and the valve-gear are similar to those of the ironclads already described, except that the motion of the valve-gear for the second cylinder is transmitted through a rocking lever to the front.

The condenser is of gun-metal, cylindrical, ⅜ inch thick, 5¼ feet in diameter outside, 7 feet long between tube-plates. It has 2627 condensing



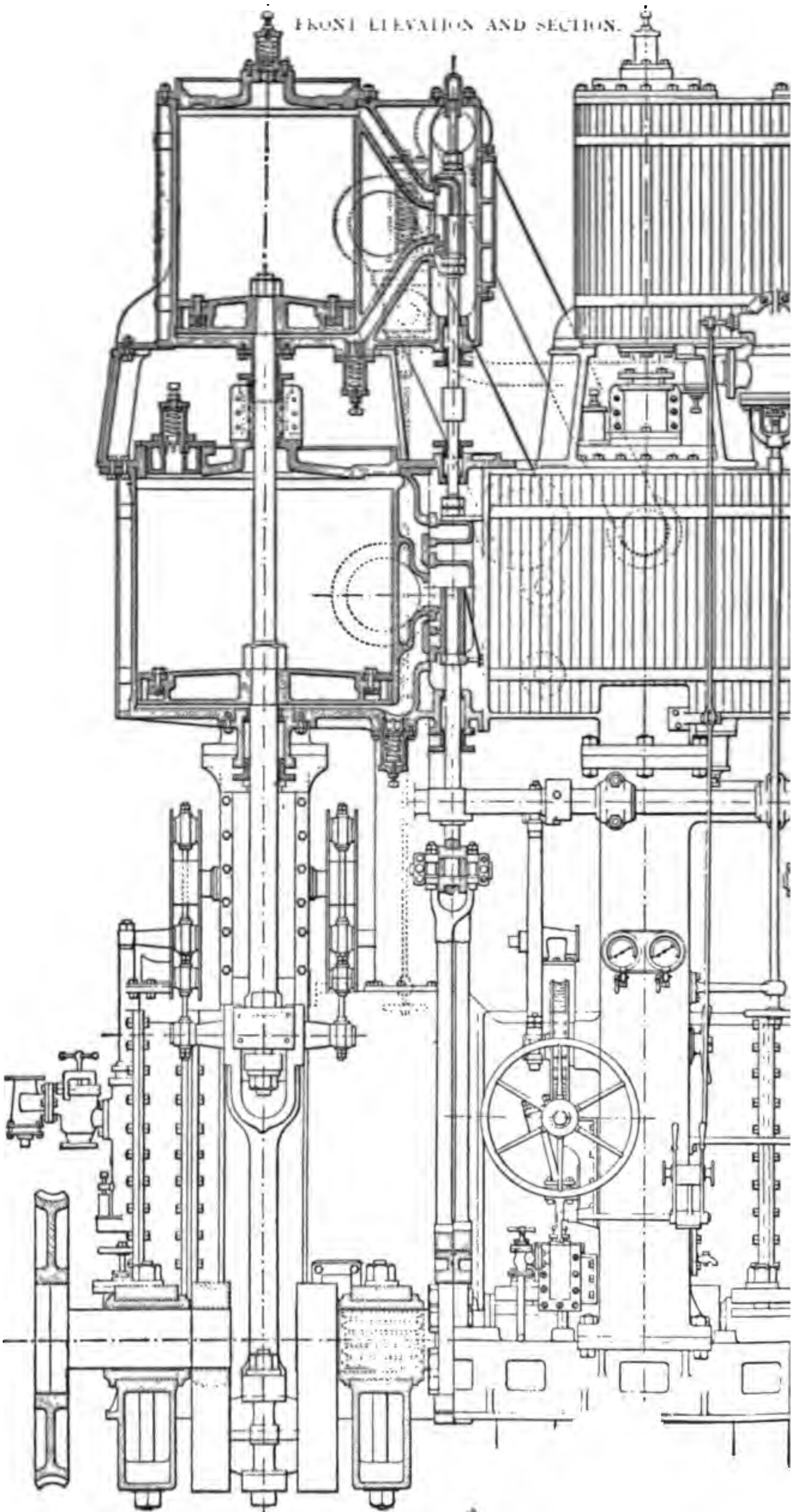
[illegible]

tubes [illegible] The steam [illegible] is circulated by [illegible]

[illegible]

[illegible] from two pairs [illegible] boilers [illegible] discharging [illegible] in diameter [illegible]

FRONT ELEVATION AND SECTION.



3rd and 4th CYLINDERS.

each having three corrugated furnace-tubes of steel, 3 feet 8 inches in diameter; and 442 flue-tubes, 2½ inches in diameter, 5 feet 8 inches long between plates.

The working pressure is 135 lbs. per square inch above the atmosphere. Each fire-grate is 3 feet 8 inches wide, 7 feet 4 inches long. The grate-area for one boiler is 80½ square feet; and the heating surface is 2281 square feet, or 28.3 times the grate-area.

The chimney is oval in section, 8 feet 5 inches by 6 feet 3 inches, of 3/16-inch plate; 50 feet 10 inches high above the level of the grates.

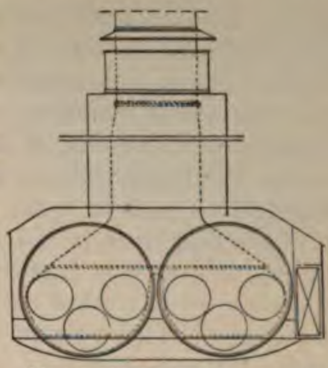


Fig. 980.—Boilers for Humphreys, Tennant, & Co.'s Horizontal Engines of Fast Cruisers. End Elevation. Scale 1/192d.

CHAPTER XC.

TRIPLE-EXPANSION DISCONNECTING TWIN-SCREW MARINE ENGINES.

DESIGNED AND CONSTRUCTED BY MESSRS. RANKIN & BLACKMORE, GREENOCK, FOR THE STEAM-SHIPS ASÇUNÇION, APA, PILCOMAYO, AND RIO PARAGUAY.

PLATE XIX*.

(Cylinders 9 inches, 18 inches, and 32 inches in diameter; stroke 22 inches.)

The twin-screw steamers above named are 160 feet in length, with 33 feet beam, and 9 feet depth of hold. The dead-weight capacity is about 500 tons. An aperture has been formed at the stern-post to allow the propellers to overlap on the system introduced by Messrs. Rankin & Blackmore in the steamship Otter, built in 1876, and since applied by them to 36 twin-screw steamers, and by other constructors in the case of the Teutonic, the Majestic, and other large vessels.

The engines are constructed on Rankin's system, patented in April, 1882, and February, 1885, whereby the advantages of triple expansion are secured without the complication entailed by two separate engines having six cylinders and six cranks, for driving twin screws. In the Rankin vertical system there are only four cylinders and two cranks; two first cylinders being placed above a second and a third cylinder, one over each of these; and the pistons of each two cylinders being fastened on one piston-rod, connected to one of the two screw-shafts below.

The two first or high-pressure cylinders are 9 inches in diameter, of ⅞-inch metal; the second is 18 inches; and the third is 32 inches in diameter, of 1-inch metal; with a common stroke of 22 inches. The capacity-ratios of the cylinders are as 1, 2, and 6.32: the two first cylinders being reckoned together as one. The cylinders are not steam-jacketed. The first cylinders are covered with asbestos, felt, and teak lagging. Steam-

jackets have been tried and, it is stated, found to be useless. The cylinders are fitted with ordinary flat slide-valves: those of each half-engine being worked by one expansion link-motion. The link is connected directly to the valve-spindle of the lower cylinder; and by means of a rocking lever of the second order, one-half of the vertical travel is transmitted from the upper end of the lower valve-spindle to the upper valve-spindle. The lap of the first valve is $\frac{3}{8}$ inch, of the other valves 1 inch. The lead of the first valve is $\frac{3}{16}$ inch at the top, $\frac{1}{4}$ inch bare at bottom; of the other valves, $\frac{1}{8}$ inch at top, $\frac{3}{16}$ inch at bottom. The travel of the first and third valves is 2 inches; of the other valves 4 inches. The throw of the eccentric is 4 inches. The main steam-pipe is $3\frac{1}{4}$ inches in diameter; the two branches to the first cylinders are $2\frac{1}{4}$ inches. The first valve cuts off at 75 per cent; the others at 70 per cent. The expansion-link or quadrant is of the double-plate style specially adapted for these engines, being unusually short in order to clear the condenser, which is located between the two half-engines. The special compactness is effected by dispensing with the usual binding bolt at each end, and employing for this purpose the pin which takes the end of the eccentric-rod. All the working parts are adjustable. The reversing is performed by means of hand levers, one to each half-engine. These can be promptly handled—a point of great importance in working single-crank engines.

The condenser, situated between the half-engines, binds them together. It contains 585 solid-drawn tubes of brass, $\frac{3}{4}$ inch in diameter externally, No. 18 wire-gauge in thickness, 5 feet in length between the tube-plates. The steam is outside the tubes, which make a condensing surface of 545 square feet. There are one air-pump and one circulating pump, double-acting, each 12 inches in diameter, with a stroke of 10 inches, contained within a continuation of the condenser casting. They, in conjunction with the feed and bilge pumps, are worked off the low-pressure main shaft by means of eccentrics keyed on the shaft. The feed-pump is fitted with metal valves; those of the circulating pump are of india-rubber. This pump passes about 100 cubic feet of water per minute.

The main shafts are of iron, $5\frac{3}{4}$ inches in diameter; the bearings are [illegible] inches long. The connecting-rods are 3 feet 8 inches long, or four times the length of the cranks; and $3\frac{1}{4}$ to $3\frac{1}{2}$ inches in diameter. The piston-rods are of iron, [illegible] inches in diameter at the upper part, [illegible] inches at the lower part. The crosshead gudgeons are each [illegible] inches in diameter, [illegible] inches long. The pistons of the two first cylinders are fitted with Ramsbottom rings of hard cast iron; the other pistons are packed with Buckley's rings and springs. Stuffing-boxes [illegible] the two first cylinders are [illegible], and replaced each by a brass gland by which friction [illegible] resistance and the [illegible] attention to packing are reduced.

When the half-engines are working together, the steam from the [illegible] first cylinders passes into the lower part of a receiver surrounding the second cylinder, divided into tw[illegible]rts by a horizontal [illegible] surrounding the cylinder midw[illegible] steam passes into the second

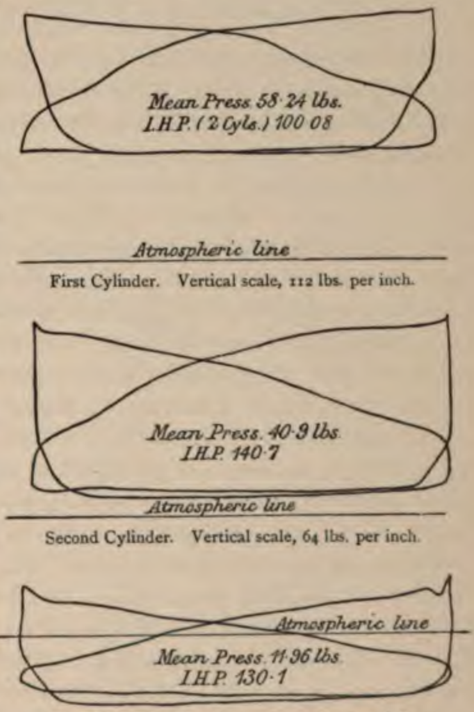
cylinder, whence it is exhausted into the upper part of the receiver, from which it advances through a horizontal connecting pipe to and through the third cylinder, whence it is exhausted into the condenser.

Assuming that the starboard engine is stopped, by the application of the reversing gear, both throttle-valves continuing open, the steam from the port high-pressure cylinder will exhaust into the lower part of the receiver, and pass thence into the second cylinder. After having acted there, it passes into the upper part of the receiver, as usual. But the starboard engine being stopped, there is no passage for the steam through the third cylinder; and the pressure rises until it is sufficient to raise the large spring-loaded valve on the receiver, shown in fig. 1, Plate XIX*., and escape into the atmosphere.

Suppose, again, that the port engine is stopped, the starboard engine alone working; the steam from the starboard high-pressure cylinder exhausts into the lower part of the receiver on the second cylinder, and accumulates there, as there is no way through the second cylinder until the pressure is high enough to lift the small spring-loaded valve, partially shown in Plate XIX*., when it passes into the upper part of the receiver, thence to the third cylinder and to the condenser.

From these explanations it is apparent that when both half-engines are at work, either both ahead or both astern, or one going ahead and the other going astern, they constitute a complete triple-expansion engine. When the port half-engine alone is working, it is in fact an engine of the compound non-condensing class. When the starboard half-engine alone is working, it becomes an engine of the compound condensing class.

Steam of 150 lbs. per square inch working pressure is supplied from a steel boiler 11 feet in diameter, 9 feet 7 inches long, having two furnace-tubes on Fox's corrugated system, 3 feet 4 inches in diameter. The fire-grates are 5¾ feet long, having 38.3 square feet of area. The fire-bars are ⅞ inch thick, with ½-inch air-spaces; with a total heating surface of 1006 square feet, or 26.2 times the grate-area. The funnel or chimney is 3½ feet in diameter, and 32 feet high above the level of the grates.



First Cylinder. Vertical scale, 112 lbs. per inch.

Second Cylinder. Vertical scale, 64 lbs. per inch.

Third Cylinder. Vertical scale, 32 lbs. per inch.

Figs. 981.—S.S. Asçunçion: Indicator Diagrams.
Steam, 150 lbs.; revolutions per minute, 124; vacuum, 26 inches.

Weight of engines, 30 tons; with water in condenser, 30¾ tons; boiler, 23 tons; with water, 36 tons; total, 66¾ tons.

The normal speed of the ship is about 8½ knots per hour, and that of the engine is 120 revolutions, or 440 feet of pistons per minute, working to 350 indicator horse-power.

The propellers are 7¼ feet in diameter, of 8-feet pitch. They have each three blades, and they overlap each other.

Sample indicator diagrams are shown in figs. 981. It is stated that about 1.6 pounds of good coal is consumed per indicator horse-power.

CHAPTER XCI.—QUADRUPLE-EXPANSION DISCONNECTIVE TWIN-SCREW MARINE ENGINES.

DESIGNED AND CONSTRUCTED BY MESSRS. RANKIN & BLACKMORE, GREENOCK, FOR THE STEAMSHIP FALLS OF INVERSNAID.

PLATE XIX*.

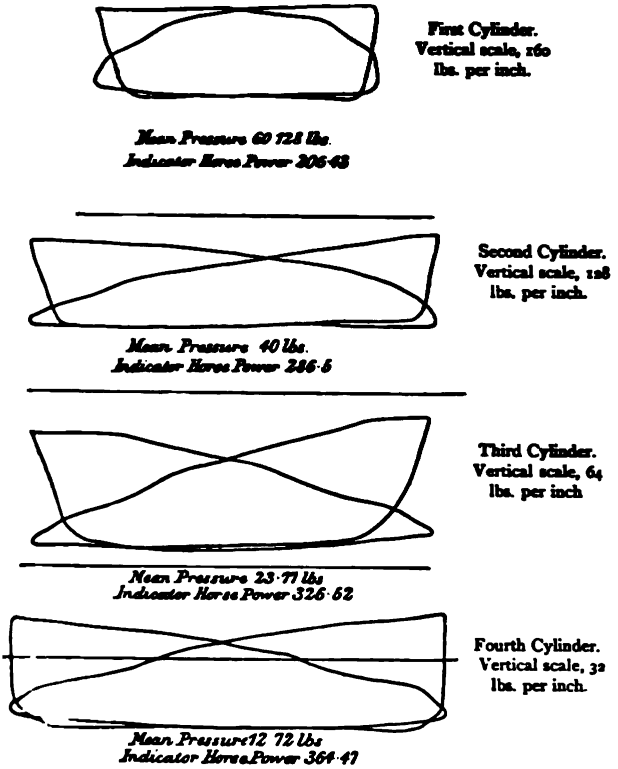
(Cylinders 18 inches, 26 inches, 36 inches, and 52 inches in diameter; stroke 39 inches.)

This steamship is 312 feet long, 40 feet 4 inches broad; depth of hold, 19 feet 7 inches. She carries 4100 tons dead-weight on a mean draught of 21 feet. In this condition she can steam at the rate of 8¾ knots per hour at sea.

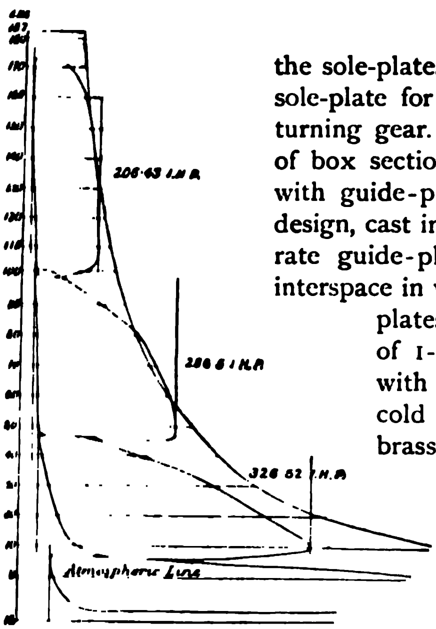
The engines are on Rankin's patented *disconnective* quadruple-expansion principle; and are similar in design to the disconnecting quadruple-expansion types, with several triple-expansion engines, patented by John F. and Matthew Rankin, in April, 1882. This appears to have been the earliest invention embracing the modern quadruple-expansion marine engine of four cylinders on two cranks. A modification of this design, having six cylinders and three cranks, was supplied by Messrs. Rankin & Blackmore for the steam-yacht Rionnag na Mara.[1]

The cylinders of the engine of the Falls of Inversnaid are 18 inches, 26 inches, 36 inches, and 52 inches in diameter; with a stroke of 39 inches. Their capacity-ratios are as 1, 2.09, 4.01, and 8.36. They are arranged as two half-engines, in tandem, working on two cranks in the main shaft. The first cylinder is placed above the second cylinder, and the third over the fourth; making practically two distinct engines, either of which may be worked independently at sea, in the event of the other breaking down. For this object a reducing valve is fitted to the lower-pressure half-engine, for the supply of steam direct from the boilers; and a special exhaust pipe is led from the high-pressure half-engine to the waste steam-pipe. The upper cylinders are connected to the lower cylinders by strong cast-iron brackets, so arranged as to admit of the lower cylinder-covers to be lifted for the purpose of examination of the pistons without disturbing the upper

[1] Described in *Engineering*, April 9, 1886, givin[illegible] [illegible]ished account of a trial of such engines.



iron covers, bolts and nuts. The crank or main shaft is 11¾ inches in diameter. It is a double-throw built shaft, forged of selected scrap iron, made in two interchangeable pieces. The sole-plate or bed-frame is one large casting of 1¼-inch and 1⅛-inch metal, of deep box section. It has four main bearing bushes of tough cast iron, lined with patent metal strips; with a cover held down by bolts with nuts recessed into guard-rings with set-pins; the bolts having collars sunk into the top of the sole-plate, against which they are secured by nuts below the sole-plate. Planed facings are provided on the sole-plate for the condenser, the columns, and the turning gear. The front columns are of cast iron, of box section, of ⅞-inch metal, and are mounted with guide-plates. The back columns are of like design, cast in one piece with the condenser. Separate guide-plates are fastened to them, with an interspace in which water may circulate to keep the plates cool. The condenser is horizontal, of 1-inch metal, and is surface-condensing, with provision for a constant circulation of cold water. It contains 829 solid-drawn brass tubes, ¾ inch in diameter outside, No. 18 wire-gauge in thickness, 9 feet 7¼ inches long between plates. The total cooling surface is 1562 square . The condenser



Figs. 983.—S.S. Holyrood: Indicator power, 1183

is also arranged for condensing by a jet in case of need. The air-pump is single-acting; the circulating pump is double-acting; and they, with the feed pump and bilge pumps, are worked by wrought-iron levers coupled at one end to the gudgeon of the connecting-rod of the after half-engine; and at the other end to the pump crosshead by double links, fitted with adjustable solid brasses secured by double nuts. The turning gear consists of a large worm-wheel fixed on the after end of the crank-shaft, moved by a worm held by a cast-iron bracket bolted on the sole-plate. It can be worked by hand, or by means of rope gearing driven by the ballast donkey engine. The propellers are of cast iron, 14¾ feet in diameter, of 15½ feet pitch; having four blades.

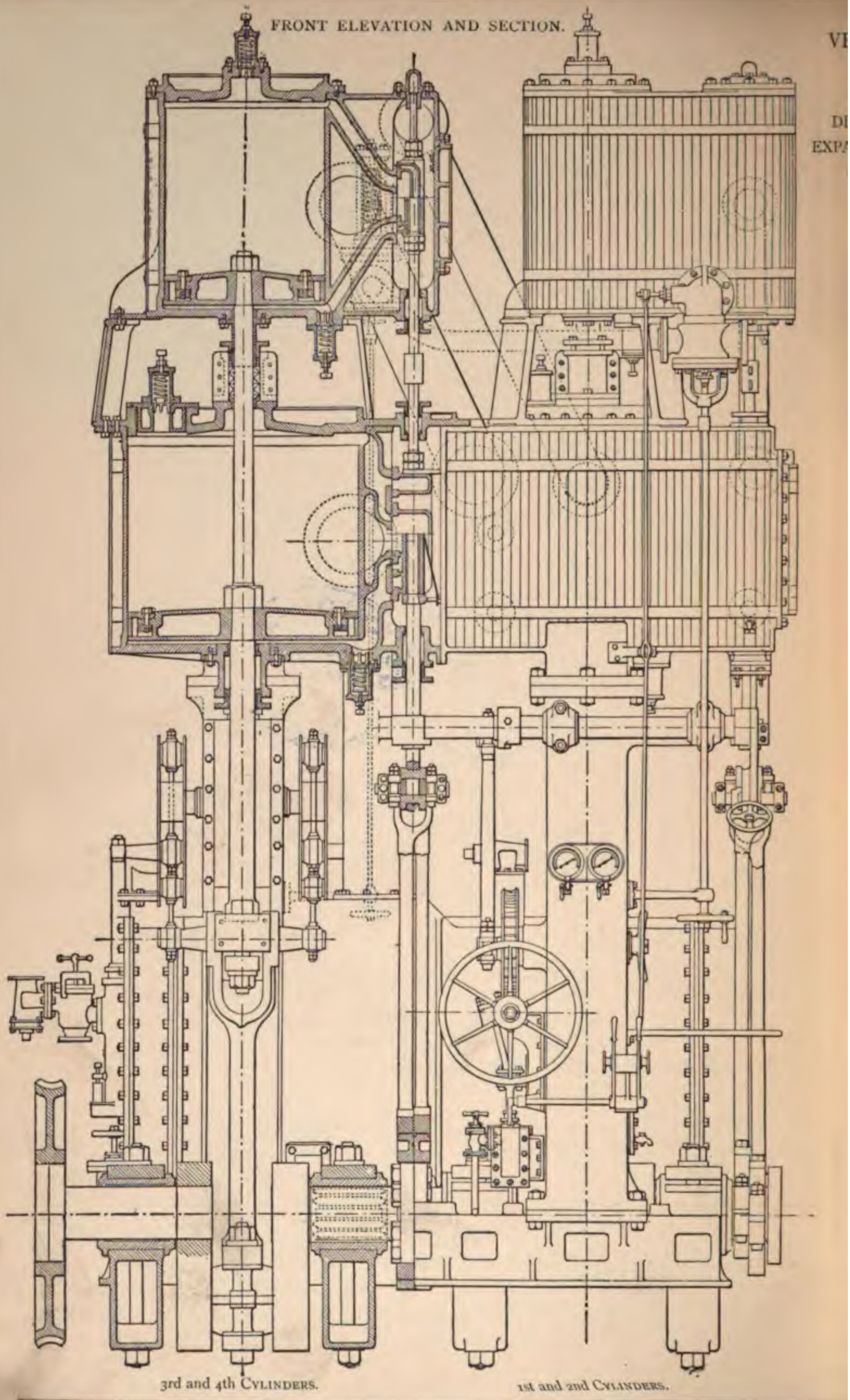
Steam is supplied from two steel boilers, under forced draught, constructed, according to Lloyds' requirements, for a working pressure of 180 lbs. per square inch. They are 13 feet in diameter, 11 feet long; of extra size in order to ensure a good supply of steam by natural draught in the event of any interruption of the forced draught. The fire-bars are ⅞ inch thick, with ½-inch air-spaces; and they are 4½ feet long. The funnel is 5½ feet in diameter, and 50 feet high above the level of the grates. The apparatus for forced draught is fitted to a closed ash-pit having automatic valves for admitting air from the stokehold, both below and above the fire-grates. The forced draught is supplied by two fans driven by Chandler's "silent" engines, which exhaust into the low-pressure casing of the main engines. Weir's hydro-kineters are employed to circulate the water in the boilers thoroughly whilst steam is being got up. One of Weir's evaporators also is adopted for supplying fresh feed-water.

Weight of engines, 115 tons; with water in condenser, 117 tons; boilers, 89 tons; with water, 125 tons; total, 242 tons.

An exact duplicate set of engines and boilers has been fitted into the new steamship Holyrood. But the apparatus for forced draught has not been applied. Thus an opportunity is afforded of testing the comparative value of the forced draught versus the natural draught. A set of sample indicator diagrams from the engine of the Holyrood, with a block diagram, are given in figs. 983. When the diagrams were taken the working pressure in the boiler was 182 lbs. per square inch; the vacuum in the condenser was 27½ inches of mercury; the speed was 68½ revolutions, or 445.5 feet of piston per minute. The total clearance at each end of the cylinders was, for the first cylinder, 8 per cent; second cylinder, 8 per cent; third cylinder, 7.1 per cent; and fourth cylinder, 5.5 per cent. The indicator power, amounting to 1183.92 horse-power, was contributed thus:—

	I.H.P.
First cylinder	206.43
Second do	286.50
Third do.	326.52
Fourth do.	364.47
Total	1183.92

FRONT ELEVATION AND SECTION.



3rd and 4th CYLINDERS.

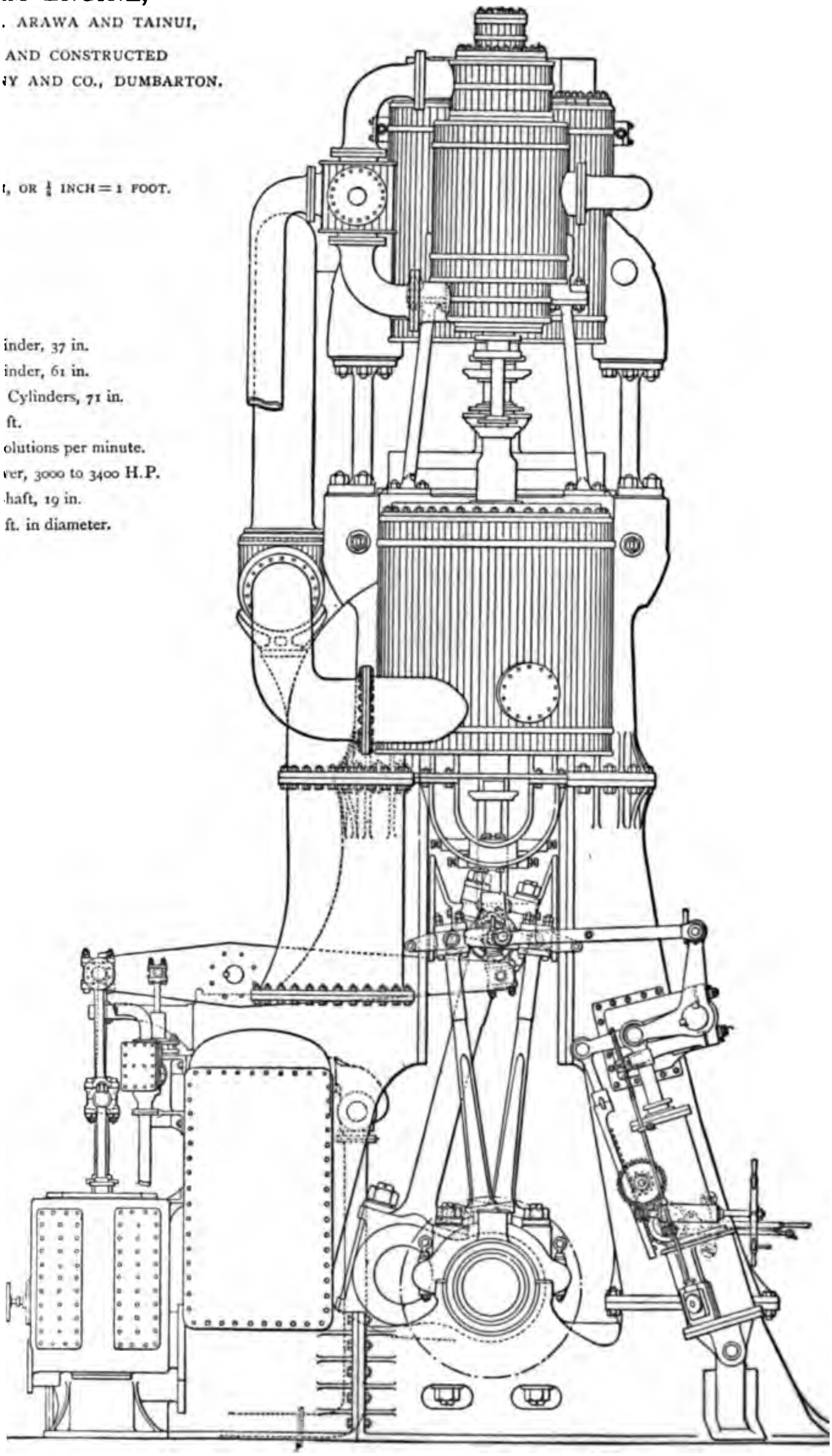
1st and 2nd CYLINDERS.

TANDEM TRIPLE-EXPANSION
M ENGINE,
. ARAWA AND TAINUI,
AND CONSTRUCTED
Y AND CO., DUMBARTON.

, OR $\frac{1}{8}$ INCH = 1 FOOT.

inder, 37 in.
inder, 61 in.
Cylinders, 71 in.
ft.
olutions per minute.
ver, 3000 to 3400 H.P.
haft, 19 in.
ft. in diameter.

FIG. 2.—SIDE ELEVATION.



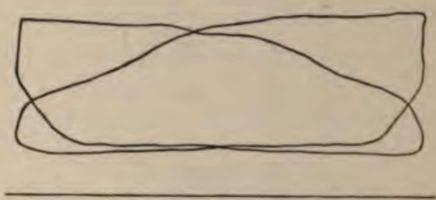
AIR-PUMP. CONDENSER. MAIN SHAFT. REVERSING GEAR

usual steam-supply and drain-pipes. It is stated that the jackets are not now used with steam except for heating up the cylinders on getting up steam, as no perceptible gain in economy could be ascertained by the use of the steam-jackets. The liners are flange-jointed to the cylinder castings at the lower ends, and are finished flush with the cylinder flanges at the upper ends.

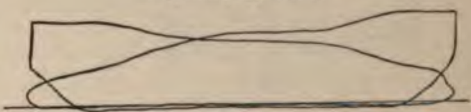
The first cylinder is fitted with a piston-valve; the other cylinders have ordinary double-ported slides, of which the second has a compensating ring on the back. The steam is cut off at 72 per cent in each cylinder in full gear ahead; and the period of admission is varied alike in all the cylinders by linking back the valve-gear. In full gear the total net or working expansion, without reckoning for clearance, is $(100 \div 72)^3$, or 2.68. At the extreme of expansive working, when the whole of the expansion is performed in the cylinders, the steam is expanded $(7.36 \div .72 =)$ 10.2 times; in which case it is assumed that there is no "drop" of pressure in the receivers, and the initial pressure in one cylinder is equal to the final pressure in the preceding cylinder.

The piston-rods are of steel, 10 inches and 8½ inches in diameter. The connecting-rods are of wrought iron, and are 10 feet long, or four times the length of the cranks. They are from 10½ inches to 9 inches in diameter.

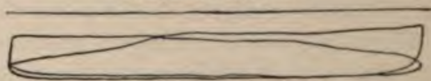
The crank-shaft is of wrought iron, 19 inches in diameter, with steel crank-pins 20 inches in diameter. The shaft is constructed in pieces bolted and keyed together. It has four bearings, each 16½ inches long. The bearings have cast-iron caps and circular cast-iron bushes lined with white metal: a system of bearing which has been practised by Messrs. Denny & Co. for the last nineteen years (since 1871) in marine engines of all sizes, with, it is stated, the most satisfactory results. The lower bushes can be removed without lifting the shaft. The journals of the crank-pins are 20 inches long.



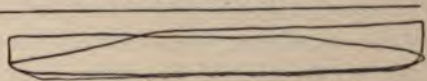
Mean effective pressure 67·2 lbs.
Scale [illegible] inch to 1 lb
1st Cylinder, 1390 I.H.P.



Mean effective pressure 21·3 lbs.
Scale [illegible] inch to 1 lb.
2d Cylinder, 1198 I.H.P.



Mean effective pressure 5·9 lbs.
Scale $\frac{1}{32}$ inch to 1 lb.
Forward 3d Cylinder, 449 I.H.P.



Mean effective pressure 6 lbs.
Scale $\frac{1}{32}$ inch to 1 lb.
Aft 3d Cylinder, 457 I.H.P.

Figs. 984.—S.S. Arawa: Indicator Diagrams with Triple Expansion. Total I.H.P., 3494.

The screw-propeller is 20 feet in diameter, with 24½ feet of pitch.

The condenser is of cast iron, 1½ inches thick; it is 18 feet 5 inches long, 4 feet wide, 8 feet 3 inches high, bolted down with forty-three 1¾-inch

bolts and nuts. There are 2240 tubes, ¾ inch in diameter outside, weighing 1 lb. per 2½ feet lineal, 16½ feet long between the plates. They are disposed hexagonally, at 1.10 inches of pitch. The condensing surface amounts to 7255 square feet. The condensing water is driven through the tubes by means of two double-acting pumps.

Steam of 160 lbs. pressure per square inch is generated in four double-ended boilers, of 1¼-inch steel plates, 13¼ feet in diameter, 14¾ feet long, having three corrugated furnace-tubes in each end of each boiler, or 24 such tubes in all, 3¼ feet in diameter outside. There are 516 iron flue-tubes, 3 inches in diameter, No. 9 gauge in thickness, at 4¼ inches of pitch,

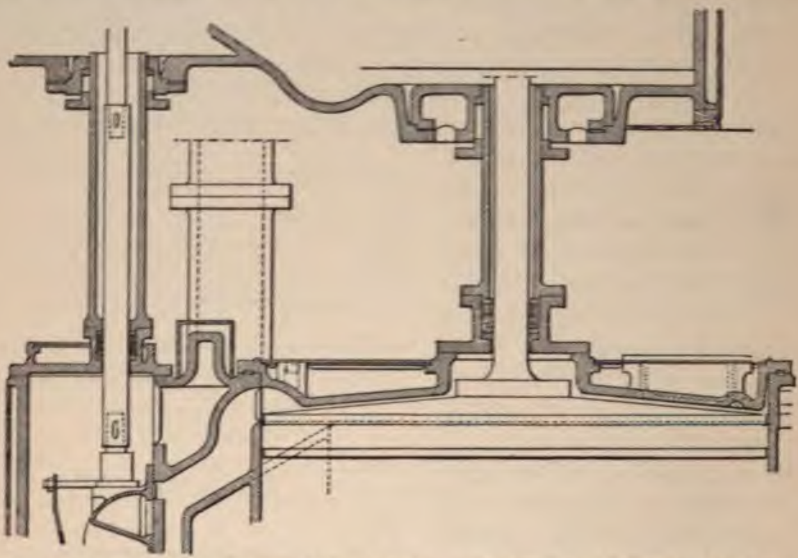


Fig. 985.—Compound Marine Engines: Connection between Upper and Lower Cylinders. Scale 1/32d.

6 feet long. There are 419 square feet of fire-grate area, and 11,220 square feet of heating surface, or 26.8 times the grate-area.

There are two funnels, of ¼-inch and 3/16-inch iron plates, 8 feet in diameter, 67 feet high above the lowest-level bars. The fire-grates are 5¾ feet long; the bars are ⅞ inch thick, with ½-inch air-spaces.

The weight of the main engines, boilers, propeller, shafting, pipes, and all connections, including the water in the boilers, is about 900 tons.

It is stated that these engines have been successful from the first. The vessels are capable of maintaining an average speed of 14 knots per hour on the voyage between England and the colonies. They are usually worked at a speed of from 60 to 62 revolutions, or 600 to 620 feet of pistons per minute, indicating from 3000 to 3400 horse-power, exemplified by the indicator diagrams, figs. 984; making a speed of from 12½ to 13 knots per hour. The rate of consumption of coal for the main engines, for voyages at the speed of 12½ knots per hour, has been found not to exceed 48 tons per day; and at the speed of 13 knots, not exceeding 54 tons per day:

corresponding to a consumption of a little under 1.6 pounds of coal per indicator horse-power per hour.

In subsequent engines of the type of the Arawa and Tainui, Messrs. Denny & Co., dispensing with the objectionable double stuffing-boxes, substituted a single metal packing for the piston-rod and the valve-rod, as shown in fig. 985, access being given to the packing when required by shifting up the pipe which surrounds the rod through the bottom of the upper cylinder or the upper valve-casing.

CHAPTER XCIII.

VERTICAL DOUBLE-COMPOUND OR QUADRUPLE-EXPANSION MARINE STEAM ENGINES OF THE S.S. SNARK.

CONSTRUCTED BY MESSRS. DENNY & CO., DUMBARTON.

(Cylinders 9¼ inches, 13 inches, 18½ inches, and 26 inches in diameter; stroke 15 inches.)

The Snark is a small vessel, built early in 1833, by and belonging to Messrs. Denny & Co.; used by them as a tender for conveying workmen and others to and from vessels on the occasions of trial trips and otherwise. Her moulded dimensions are 81 feet by 16 feet by 7¾ feet. The engines originally were a pair of compound engines having cylinders 12½ inches and 22 inches in diameter, with a stroke of 15 inches; in the ratio 1 to 3.10. They were constructed for a working pressure provisionally of 90 lbs. per square inch; though the boilers were made capable of a pressure of 120 lbs. with a view to subsequently tripling or quadrupling the cylinders. The engines were first converted for triple expansion, by the addition of a high-pressure cylinder on the top of the originally first cylinder; and next for quadruple expansion, by the addition of another cylinder above the low-pressure cylinder. Afterwards the cylinders were replaced by others constructed for quadruple expansion, according to the latest patent of Mr. Walter Brock, for tandem cylinders, as illustrated by figs. 986 to 988, described by Mr. Brock as the substitution of a pair of compound tandem high-pressure cylinders, and a pair of compound tandem low-pressure cylinders, for the original first and second cylinders respectively. Hence he describes the aggregate structure as "double compound engines." Mr. Brock's first patent was taken out in March, 1884, and his second in June, 1885.

The upper cylinders have no valves or pipes in connection; and they can be lifted with nearly as much ease as ordinary cylinder-covers. The distributing valves for all the cylinders are in casings attached to the lower cylinders; and there are only the same number of stuffing-boxes as in an ordinary compound engine.

The high-pressure tandem cylinders are 9¼ inches and 13 inches in diameter, and the low-pressure tandem cylinders are 18½ inches and 26 inches in diameter; with a stroke of 15 inches. The capacity-ratios are

as 1, 2, 4, 8. Steam is distributed to each pair of cylinders by a combination of a piston-valve for the first cylinder of each pair, and a flat slide-valve for the second, on one spindle, worked by an ordinary link-motion. The upper pistons of each piston-valve are 4 inches and 8½ inches in diameter respectively; they are larger than the lower pistons, so as by the excess of upward steam pressure to balance the weight of the valves and

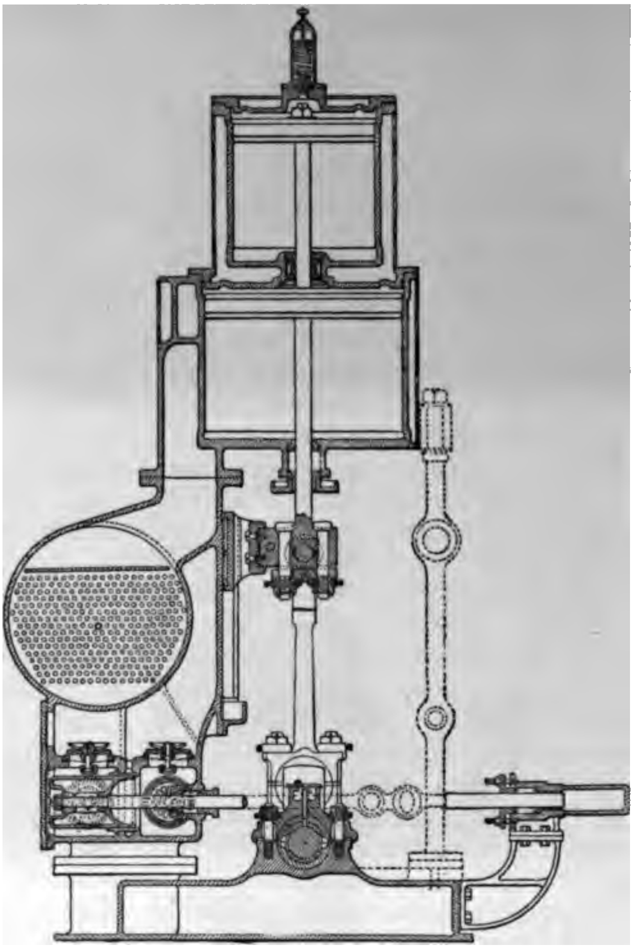


Fig. 986.—Denny's Quadruple-expansion Engine: Cross Section. Scale 1/24th.

their spindles. The metallic packing between the two cylinders is on the system of Messrs. Marshall and Thunder, consists of cast-iron rings, each of which is in three segments having tongue pieces, kept lightly in contact with the piston-rods by means of spiral springs stretched round the rings outside. It is believed that for surfaces working on each other in steam, cast iron is the best material that can be employed, and accordingly the piston-rods of the first cylinders are cased with cast iron, as shown in section in one of the cylinders, fig. 987. These rings and rods of cast iron,

as applied to the engines of the Snark, proved, after six months of nearly continual work, to be in first-rate order, both rods and rings having brightly burnished and perfectly smooth surfaces.

The upper pistons and the piston-valves are packed with two eccentric spring-rings of cast iron, one within the other, intended to act practically as plugs, which in fact they become in a very short time, the initial spring

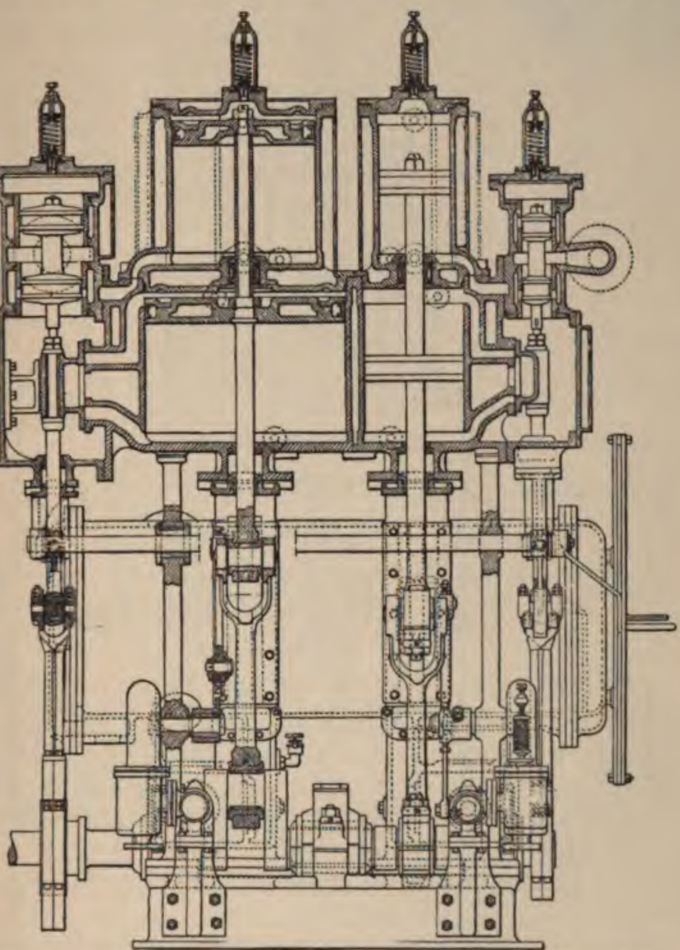


Fig. 987.—Quadruple-expansion Marine Steam Engines of S.S. Snark, by Denny & Co. Longitudinal Vertical Section. Scale 1/24th.

of the rings being very slight. The packing rings of the lower pistons are fitted on Mr. Haythorn's system. They are clear of the bodies of the pistons, and are free to adapt themselves to the cylinders independently of the pistons; so providing compensation for any slight inaccuracy or deviation in the axial lines of the cylinders. The rings, fig. 989, are expanded by means of a helical spring abutting on the ends of a circular line of jointed links inlaid at the back of the ring. The pressure set up

by the line of links is adjustable by means of a right-and-left-hand screw in the line of links, the action of the screw being transmitted to the helical spring. This system of packing has worked perfectly in the engines of the Snark.

The condenser is of cast iron, ⅝ inch thick for the cylindrical part. There are 316 tubes, ¾ inch in diameter, 5¼ feet long between the plates,

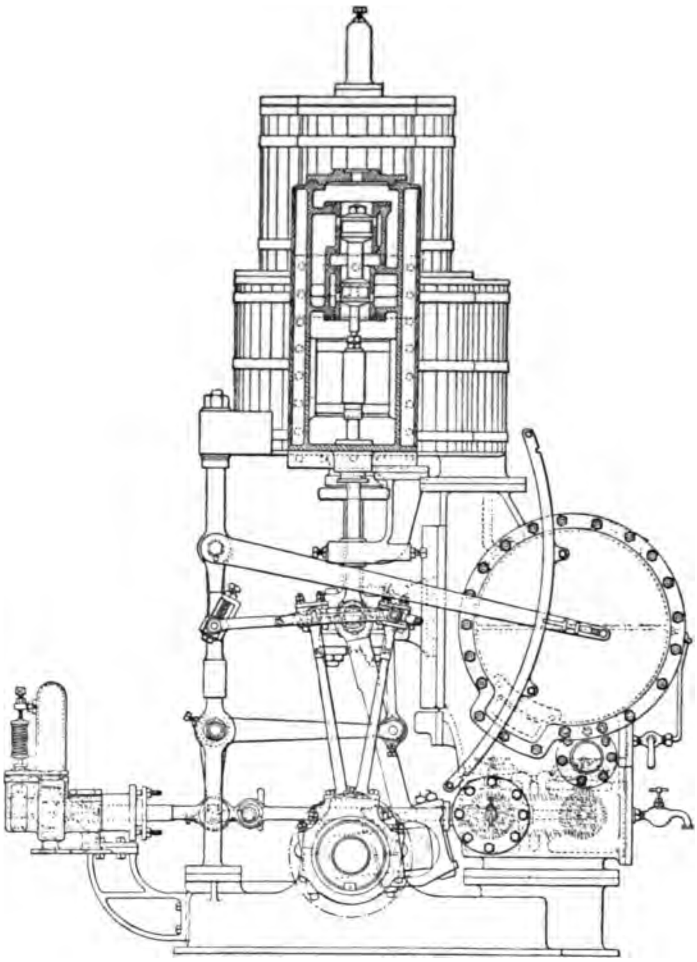


Fig. 988.—Denny's Quadruple-Expansion Engines for S.S. Snark: End Elevation. Scale 1/24th.

making 324 square feet of surface. The condensing water circulates inside the tubes.

The air-pump and the circulating pump for the condenser are horizontal, double-acting, worked by bell-crank levers, one from each piston-rod head. By measurement of the actual steam and priming water passed through the engine, as delivered by the air-pump, a saving of nearly 4 per cent has been proved in compa[illegible] th the triple-expansion engine working at the same pressure[illegible] le-compound engine, it is con-

tended, is simpler than the three-cylinder engine, with fewer working parts, more easily taken to pieces, and demanding less attention when working. Existing compound engines can be easily converted in this way by simply replacing the cylinder by new tandem cylinders, supplying at the same time new boilers for high pres sure.

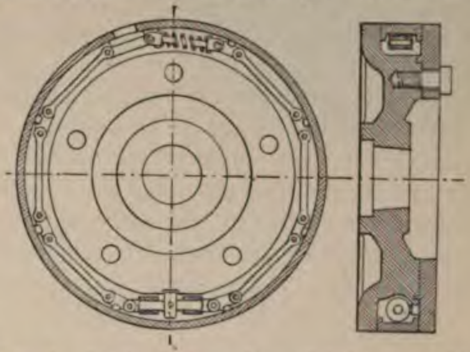


Fig. 989.—S.S. Snark: Piston of No. 2 Cylinder. Scale 1/8th.

The engines make 150 turns per minute, and develop 150 indicator horse-power, consuming 14½ pounds of water per horse-power per hour. Steam is supplied from one cylindrical boiler, 8 feet in diameter, 7 feet long, having one furnace tube, corrugated, 3 feet 8 inches in diameter inside, and 2½-inch flue-tubes 5 feet long. The area of fire-grate is 18.75 square feet, and there is 441 square feet of heating surface, which is 23½ times the grate-area. The working steam pressure is 120 lbs. per square inch.

CHAPTER XCIV.—QUADRUPLE-EXPANSION MARINE STEAM ENGINES.

CONSTRUCTED BY MESSRS. DENNY & CO., DUMBARTON, FOR THE STEAM-SHIPS BUENOS AIRES AND MONTE VIDEO, OF THE COMPANIA TRANSATLANTICA OF BARCELONA.

PLATE XXI.

(Cylinders 32 inches, 46½ inches, 64½ inches, and 92 inches; strokes 5 feet.)

These ships are 410 feet long, 48 feet broad, 32 feet deep, moulded.

These quadruple-expansion engines are, like those of the Snark, already noticed, on the system patented by Mr. Walter Brock. The system differs from the ordinary compound engine, in the substitution of two tandem cylinders for the single high-pressure cylinder; and of other two tandem cylinders for the single low-pressure cylinder—four cylinders with continous expansion on two cranks. The first and second cylinders are on one piston-rod, with crank; and the third and fourth cylinders are on the second piston-rod with crank. A special feature is the absence of valve-chests and of pipe connections on the upper cylinders. The distributing valves for all the cylinders are in casings attached to the lower cylinders. The number of stuffing-boxes is the same as for an ordinary compound engine. The upper cylinders, thus unencumbered, can be lifted from their places with nearly as much facility as ordinary cylinder-covers. But the uplifting of the upper cylinders is seldom necessary, for direct access to the lower cylinders can be had through openings in the top or cover of the lower cylinder, which are closed by doors. When the lower cylinders

are too small to afford the requisite access by doorways, the upper cylinders may readily be lifted clear. Two door openings are formed in the bottom of each of the upper cylinders, which give access to the metal packing-rings of the piston-rods. On this system of conical formation, which was designed some years ago by Dr. A. C. Kirk, the pistons are coniform, in a single thickness, of cast steel, to which the forms of the ends of the cylinders are adapted.

The upper cylinders have piston-valves: one valve to the first cylinder and two valves to the third cylinder. The lower cylinders have double-ported flat slide-valves of the usual kind: one to the second cylinder and two to the fourth cylinder. Each piston-valve and its consecutive slide-valve are mounted on the same spindle, and contained in the same casing. The spindles of the double valves are united underneath the stuffing-boxes by a crosshead. The piston-valves are withdrawn when required through doorways in the tops of the casings. The lower valves can be slipped off their spindles, and withdrawn with facility, through doorways at the sides.

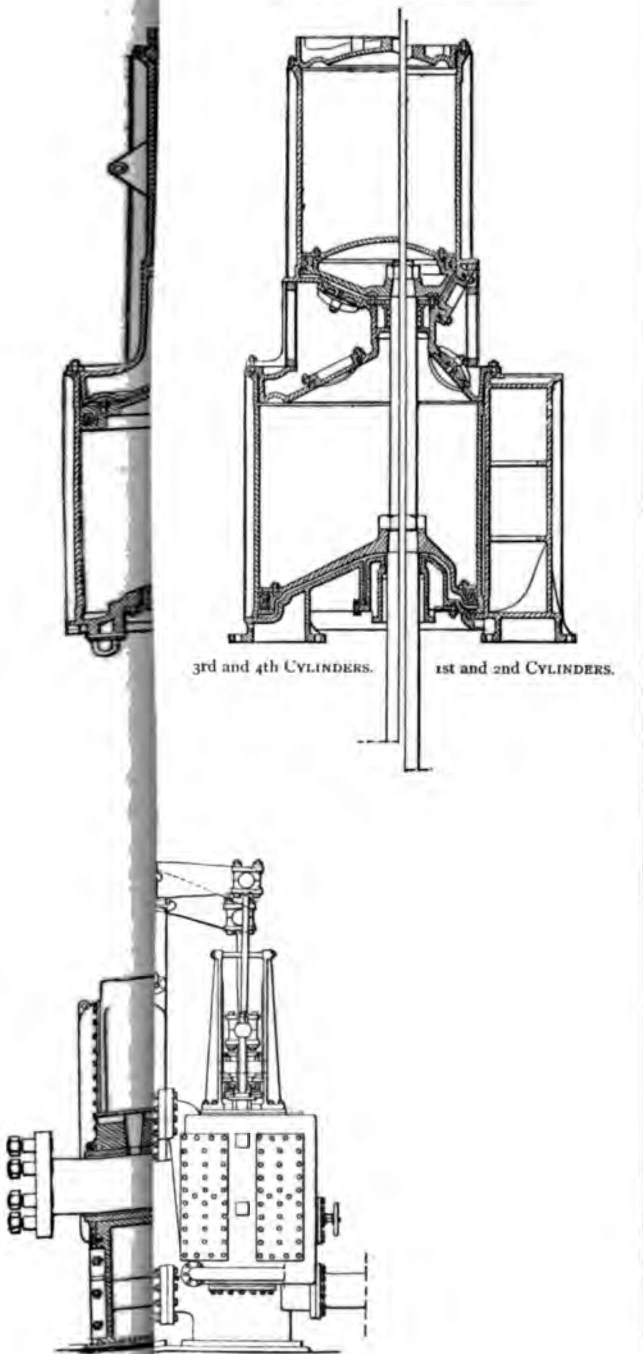
The upper piston of each piston-valve is larger in diameter than the lower piston; so that by the consequent excess of upward steam pressure, the weight of all the valves and gear may be balanced in any required proportion.

Steam from the boiler enters the engine by a pipe or passage formed between the two pistons of the first cylinder valve, whence it is distributed to the upper and lower ends of the cylinder. Thus, the only portion of the engine exposed to the full boiler pressure is the small part of the valve-casing between the pistons of the first valve and the first cylinder itself. The steam is exhausted from the first cylinder over the ends and down the centre of the piston-valve direct into the valve-casing beneath. This casing is made of considerable capacity in order to form a suitable receiver between the first and second cylinders; sufficiently large to admit of the steam being cut off to the second cylinder sufficiently early for maintaining the pressure there, and preventing the exhaust back pressure in the first cylinder from falling too low. From the valve-casing the steam is distributed to the second cylinder in the usual way, and is thence exhausted into a receiver cast round the cylinder. Hence it proceeds to the third cylinder, entering the passage between the pistons of the valve, and passing through the third and fourth cylinders, and finally being exhausted into the condenser. The valves are worked by means of the bar link-motion.

The cylinders are 32 inches, 46½ inches, 64½ inches, and 92 inches in diameter, with a common stroke of 5 feet; having the capacity-ratios as 1, 2.11, 4.06, and 8.27. The working pressure in the boilers is 180 lbs. per square inch. The crank-shaft is of iron, 18 inches in diameter, having bearings 25½ inches long. The crank-pins are of steel, 18 inches in diameter, with bearings 19 inches long. The piston-rods are of steel, 6⅝ inches in diameter above, 9 inches below. The connecting-rods are of iron, 10 feet long, or four times the length of the crank. The surface condenser contains 1303 tubes, ¾ inch [illegible] outside, 18 feet 2¼ inches

NTE VIDEO.

FIG. 3.—VERTICAL SECTIONS.



AIR-PUMPS.

long, No. 18 wire-gauge in thickness, presenting 4605 square feet of condensing surface, the steam being condensed on the outsides of the tubes. There are two vertical single-acting air-pumps, 26 inches in diameter, with a stroke of 2 feet, worked by levers off the crossheads, with a leverage of 2½ to 1. By the same means are worked two 5½-inch feed-pumps and two 5½-inch bilge-pumps, having plungers of brass and cast iron respectively; and a 6-inch steward's pump, with a stroke of 12 inches, on the back of the condenser.

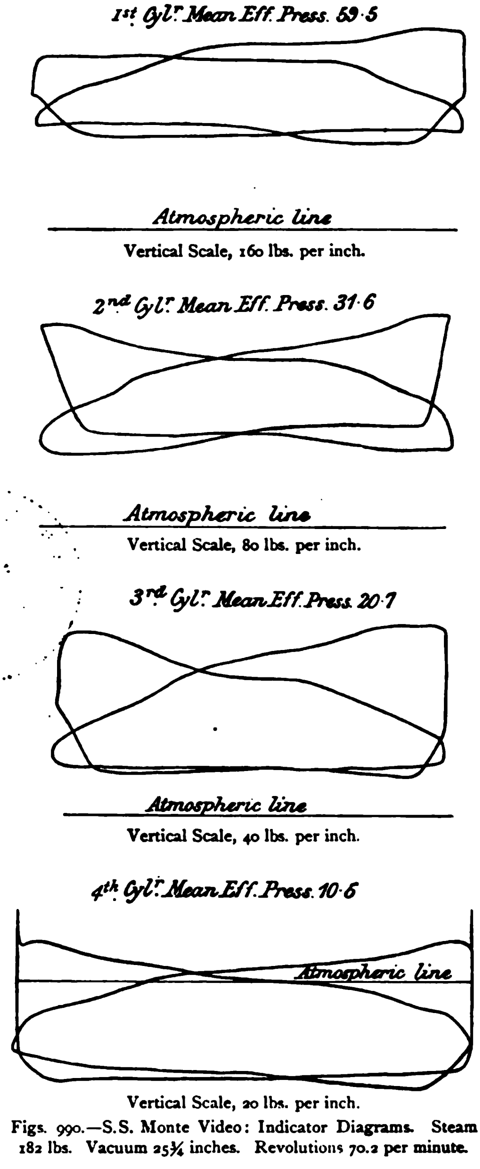
The propeller has four blades, and is 19½ feet in diameter, with a pitch of 25 feet.

Steam is supplied from three cylindrical double-ended return-tube boilers, 14 feet 2 inches in mean diameter, 17½ feet long; having three corrugated furnaces at each end of each boiler, or 18 furnaces in all. There is 352 square feet of fire-grate area, and 9630 square feet of heating surface, 27.3 times the grate-area.

The weight of the engines, shafting, propeller, piping, and connections is 371 tons; and that of the boilers with water is 354 tons; together, 725 tons.

The power developed by the Monte Video, on a trial trip, was 5080 indicator horse-power, contributed as follows:—

	I.H.P.	I.H.P.
First cylinder	1019	2159
Second do.	1140	
Third do.	1439	2921
Fourth do.	1482	
Total	5080	



Vertical Scale, 20 lbs. per inch.

Figs. 990.—S.S. Monte Video: Indicator Diagrams. Steam 182 lbs. Vacuum 25¾ inches. Revolutions 70.2 per minute.

On that occasion the average steam pressure in the boiler was 182 lbs. per square inch; the vacuum was 25¾ inches of mercury; the average speed of the engines 70.2 revolutions per minute; and that of the vessel, 15.97 knots per hour. The sample indicator diagrams from which the power was calculated are shown in figs. 990.

From the results of careful observations, it is estimated that, with a working pressure 180 lbs. per square inch in the boiler—but little in excess of the usual pressure employed for triple-expansion engines—an economy of from 6 per cent to 8 per cent of coal has been effected with this quadruple-expansion engine, compared with triple-expansion engines.

The first sea-going steam-ship that was converted on Mr. Brock's system was the Tenasserim, belonging to the British and Burmese Steam Navigation Company, of Glasgow and London, which was turned out after conversion in October, 1887. The two compound steam cylinders that were removed were 47 inches and 82 inches in diameter; and in their place were substituted four cylinders, 24½ inches, 37 inches, 49 inches, and 72 inches in diameter. The stroke in both cases was 3½ feet. Four single-ended boilers, under 60 lbs. pressure, were replaced by two double-ended boilers for 180 lbs. pressure. An increase of 40 per cent of power was effected by the alteration, with an increase of speed from 8.75 knots to 9.84 knots per hour, and a reduction of about 9 per cent in consumption of coal—from 26 tons 7 cwts. to 24 tons per day. Making 60 revolutions per minute, 1700 indicator horse-power was developed.

CHAPTER XCV.—COMPOUND OSCILLATING ENGINES OF H.M.S. SPHINX.

CONSTRUCTED BY MESSRS. JOHN PENN & SONS, GREENWICH.

(Cylinders 38 inches and 70 inches in diameter; stroke 4½ feet.)

H.M.S. Sphinx is a composite paddle-vessel of 1130 tons, built in 1883 by Messrs. Green of Blackwall, for service in the Persian Gulf. The engines, figs. 901, 902, and 903, are oscillating. The cylinders oscillate on trunnions, vertically under the paddle-shaft; connecting-rods being dispensed with, and the required compactness secured.

The framing is of cast iron, of 1-inch metal for the most part. The sole is in three pieces, bolted together; the top in four pieces, bolted together, forming three bays for the play of the cranks; and supported on eight 4½-inch round columns of wrought iron, fastened to the sole. The framing is stiffened by cast-iron diagonals at each end of the engine.

The paddle-shaft is of Whitworth fluid-compressed steel, about 13½ inches in diameter at the cranks, 12½ inches at the paddles, hollow, 7 inches in diameter inside. There are four bearings, 21 inches long, for the shaft on the top frame of the engine, and three cranks. Of these the middle crank is forged solid with the intermediate shaft, having a 13½-inch pin, 7 inches long, with a 4-inch through hole. The other cranks and crank-pins, for the connection of the piston-rods, are of steel, separately constructed; the cranks are shrunk on the shaft, and the crank-pins are each cottered into one arm of the crank and fit into and through the other arm. The centre-line of the shaft is 10¾ feet above the level of the bottom of the base framing.

The first and second cylinders are 38 inches and 70 inches in diameter, having the area-ratio of 1 to 3.4, with a stroke of 4½ feet. They are 11 feet 1 inch apart between centre-lines. They are thoroughly steam-jacketed, and felted and lagged. The liner of the first cylinder is of Whit-

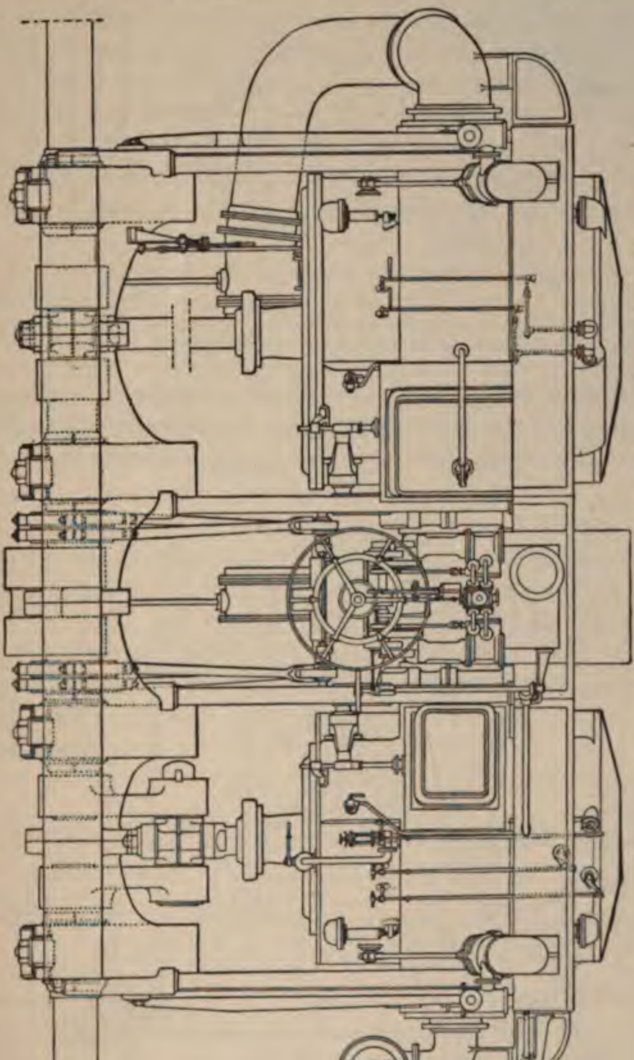


Fig. 991.—Compound Oscillating Marine Steam Engine for H.M.S. Sphinx, 1140 I.H.P. Elevation. By John Penn & Sons, London. Scale 1/48th.

worth steel; that of the second is of cast iron. The steam is exhausted from the first cylinder into a receiver which is cast around the cylinder; whence it passes into the second cylinder, and thence into the condenser. The distribution of the steam is effected by means of two slide-valves for each cylinder, one at each side of the trunnion, for the operations of admission and exhaust. The condenser is of sheet brass and gun-metal,

surface-condensing; containing 2068 horizontal tubes of solid-drawn brass, tinned inside and outside. The steam is condensed within the tubes, and

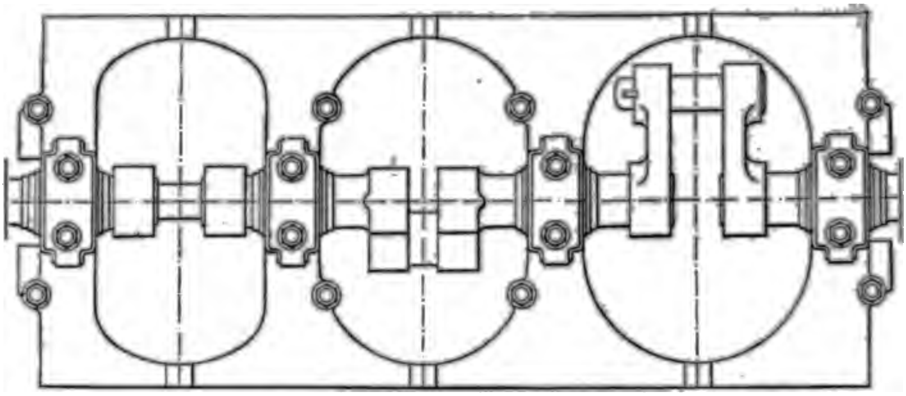


Fig. 992.—Penn's Compound Oscillating Engine: Plan of Upper Frame. Scale 1/48th.

the condensing water is circulated through the condenser, outside the tubes, by means of a centrifugal pump driven by an independent engine. This pump can also draw water from the bilge in case of leaks in the hull; and

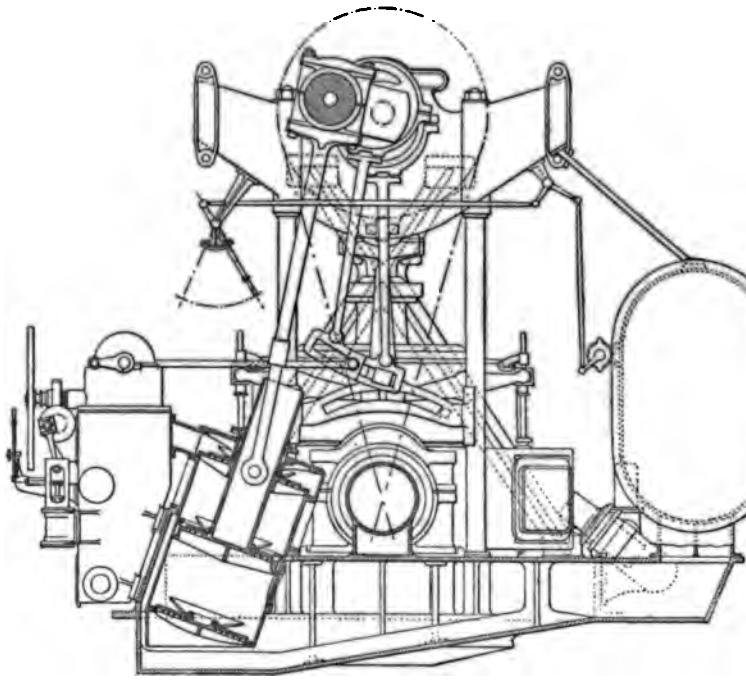


Fig. 993.—Penn's Compound Oscillating Engine: Section through Air-pump. Scale 1/48th.

is capable of discharging 200 tons of water per hour, with a steam-pressure of 40 lbs. per square inch.

The air-pump is of brass, single-acting, 2 feet 4½ inches in diameter, with bucket and top and bottom disc-valves of india-rubber. The stroke

is 27 inches. The bucket is formed with an 11-inch trunk, within which the connecting-rod takes its connection.

The pistons are of cast iron, fitted with packing-rings of cast iron, held out with steel springs. The piston-rods are of steel, 8 inches in diameter, having the usual cap-and-bolt connection to the crank-pins.

The paddle-wheels are feathering, 18 feet 1½ inches in diameter, measured to the outer edges of the floats. There are nine floats, each 8¾ feet long, 3 feet 2 inches wide.

There are two feed-pumps and two bilge-pumps, driven from the main engines, each 9 inches in diameter, with a stroke of 15 inches. There are, in addition to these, an auxiliary feed-engine and an auxiliary bilge-engine.

The working pressure in the boilers is 75 lbs. per square inch. There are two cylindrical boilers, 12½ feet in diameter, 9½ feet long, of steel plates ⅞ inch thick for the shell. The furnaces and other parts are of iron. Each boiler contains three plain 3-feet furnace-tubes, discharging into a separate combustion-chamber for each; and 251 tubes, 3 inches in diameter outside, 6 feet 7½ inches long between the plates. Of these, 192 are of brass and the remaining 59 are iron stay-tubes. Both boilers are required for the supply of steam when working at full power.

The contract power of the engines was 1000 indicator horse-power, though, on the six-hours' full-power trial, 1140 horse-power was indicated, when the engines worked at a speed of 35 turns, or 315 feet of piston, per minute. The steam was cut off at ⅝ths of the stroke in each cylinder, making a nominal expansion of $(3.4 \times {}^8/_5 =)$ 5.44. It is stated that the consumption of coal on the trial was at the rate of 1.85 pounds per indicator horse-power per hour.

CHAPTER XCVI.

PAIR OF DIAGONAL COMPOUND CONDENSING PADDLE ENGINES, FOR THE S.S. SERAJUNGE.

CONSTRUCTED BY MESSRS. T. BATES & CO. (POLLIT & WIGZELL), SOWERBY BRIDGE.

(Cylinders 27 inches and 54 inches in diameter; stroke 5 feet.)

These diagonal engines, figs. 994 and 995, were constructed for the paddle steamer Serajunge, the property of the India General Steam Navigation Company, Calcutta, for the river service between Calcutta and Assam, carrying deck cargo, and towing flats. The boat is of iron, 280 feet long, with 30 feet beam, and is 10 feet deep. The draught, empty, is 2 feet; fully loaded, 4½ feet.

The two engines are side by side, one on each side of the centre-line of the boat, entirely independent of each other; each engine driving one paddle-wheel. The cylinders are inclined at an angle of 1 vertically in 2.6 horizontally; and the direct height of the axis of the crank a' bed is 9 feet 4½ inches.

The framing of each pair of engines consists of three cast-iron girder-pieces, of $1\frac{3}{8}$-inch metal, bolted to the upper ends of the cylinders, and

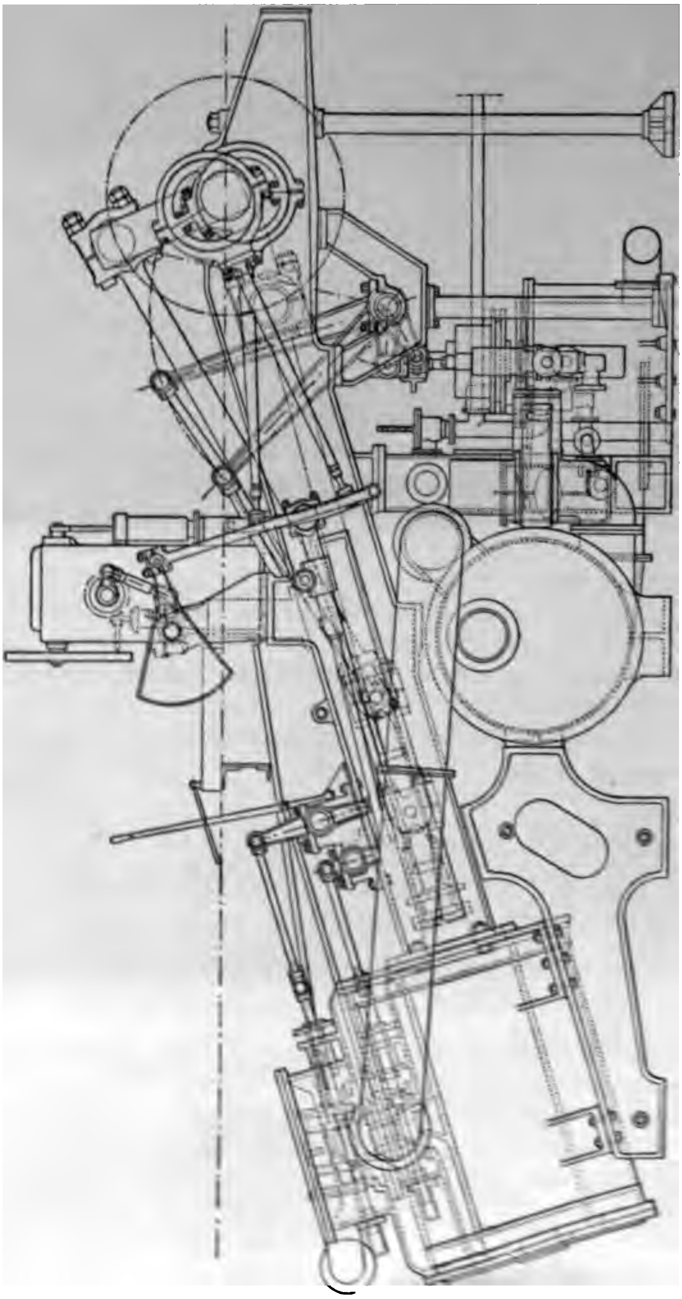


Fig. 714. Diagonal Compound Marine Steam Engine, by T. Bates & Co. (Pollit & Wigzell). Side Elevation. Scale 1/48th.

giving three bearings to the crank ... are extended forward beyond the crank-shaft, to the ... d are tied to-

gether by a transverse plate. The girders are supported at the higher ends on 5-inch round wrought-iron columns, in cast-iron bases, 12 inches square,

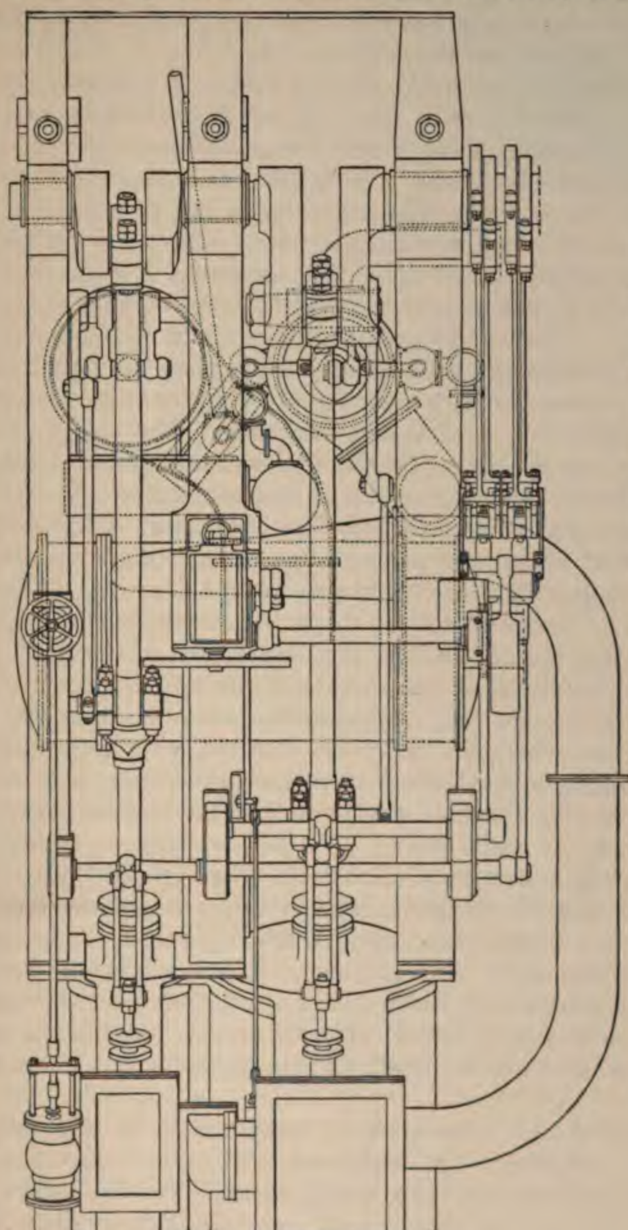


Fig. 995.—Diagonal Compound Marine Steam Engine, by T. Bates & Co. (Pollit & Wigzell). Plan. Scale 1/48th.

to suit the engine-bearers in the boat; and they are additionally suppor
on the condenser and on supplementary frame-castings, which su

the cylinders. The slide-guides for the crossheads are cast on the girders; also, facings for the fixings of the valve-gear and starting-gear.

The engine-bearers are wrought-iron box-girders, of ¾-inch plates, 10½ inches deep, built into the ship's bottom.

The cylinders are 27 inches and 54 inches in diameter, of 1¼-inch metal, with a stroke of 5 feet. The ratio of their areas is 1 to 4. They are not steam-jacketed, and are covered with non-conducting material and lagged with polished mahogany. The pistons are 1 inch clear of the covers at the ends of the strokes. The valve-chests and passages are of 1-inch metal. The distribution for each cylinder is effected with an ordinary slide-valve, on a three-ported face. The steam-ports of the first cylinder are 2¾ inches by 14 inches; and those of the second cylinder are 4½ inches by 26 inches; $^1/_{18.1}$ part and $^1/_{25}$ part of the respective cylinder-areas. The travels of the valves in full-gear forward are 7 inches and 10 inches. The maximum admission for each cylinder is 75 per cent of the stroke; and the cut-off is varied by means of link-motions. The cranks are at right angles. There is no special receiver, but the intermediate available capacity of steam-passages, pipes, &c., is equal to that of the first cylinder.

The condenser is of ¾-inch cast iron, cylindrical, 4 feet in diameter; fixed transversely underneath the main girders, and bolted to them and to the ship's bearings. There are 1056 solid-drawn brass tubes, ¾ inch outside diameter, No. 16 gauge in thickness, pitched at about 1⅔ inches, 6 feet long between the plates; making 1250 square feet of condensing surface. The steam is exhausted on the outside of the tubes, and the condensing water circulates through them. The tube-plates are of cast iron, 2 inches in thickness, into which the tubes are fastened with wood ferules. The circulating pump is single-acting, 26 inches in diameter, with a stroke of 15 inches, worked by means of a bell-crank off the first crosshead.

The air-pump is single-acting, 36 inches in diameter, with a stroke of 15 inches, worked off the second crosshead. The hot-well is placed between the condenser and the air-pump, and it forms a support for the main girders. It has a 6-inch outlet, through the ship's side. It has a float for regulating the suction for the feed-pump. The float is hung from one end of a lever, the other end of which controls a throttle-valve on the suction-pipe of the feed-pump, by which, when the water-supply in the hot-well is deficient, the suction-pipe is closed, and the pumping of air into the boiler is prevented.

The piston of each cylinder is 10 inches thick; in one piece, hollow, with a narrow junk-ring. The first piston is of 1½-inch metal in the faces, and the second is of 1¾-inch metal, reduced to 1½ inches near the periphery. The packing rings are of cast iron, two to each piston, are of L section, on Mather & Platt's principle, with an improved steel coil. They are together 6 inches wide on the face. The piston-rods are of steel, 5¼ inches in diameter, each let into the piston with a taper, and fastened with a nut · d. The outer end of the piston-rod is formed with a head to head, which is fastened to the piston-head with a cap

and two bolts. The connecting-rods are 11 feet in length, or 4.40 times the length of the cranks. They have solid-forged ends to take the crosshead, and cap-and-bolts fastening on the crank-pins.

The crank-shaft is in two pieces:—the crank-axle of the first cylinder, and the paddle-shaft. The crank-axle is of cast steel, having 9-inch journals. The paddle-shaft is of wrought iron. It is 11 inches in diameter.

The crank-arms for the second cylinder are of wrought iron. The centres are 11 inches deep, and the webs of the inner and outer cranks are respectively 8 inches and 7 inches thick. They are shrunk on the ends of the steel crank-axle and the paddle-shaft respectively, and secured with a cylindrical key driven in from the face of each crank. The crank-pin is of steel, 9 inches in diameter, let into one of the arms with a taper and fastened with a shallow nut. The other end of the pin is cylindrical, and is let into the crank on the paddle-shaft, which is bushed to receive it. The main bearings are fitted with wedge-blocks and screws.

The valve-gear consists of ordinary shifting-link motions, one for each cylinder. The two motions are side by side, at the outer sides of the engines, the motion being conveyed to the valve-spindles through transverse rocking shafts. The link-gear is balanced by a counterweight on the reversing shaft; and the operation of reversing is effected by the application of steam power to a single-acting 5-inch cylinder, having a 10-inch stroke, the shaft of which carries a worm, which drives a worm-wheel, on the shaft of which a 6-inch crank is fastened, and revolves. The crank is linked to the weighted lever on the reversing shaft, and by its revolution lowers or raises the links for forward or backward gear.

From the ends of the crosshead of the circulating pump a 4½-inch feed-pump, with a 15-in. stroke, and a bilge-pump of the same capacity, are worked.

The paddle-wheels are 19½ feet in diameter, having floats 10 feet long, 2¼ feet wide.

Steam is supplied by six Scott's tubular boilers, all of steel—three forward and three aft, the two groups being connected with an 8-inch copper steam-pipe from each group, to an 11-inch main, from which steam is conveyed to each engine by an 8-inch branch. The boilers are each 5½ feet in diameter, of ½-inch shell-plates, except the ends, $^{11}/_{16}$ inch thick. There are 60 flue-tubes, 3½ inches in diameter, 9 feet long between the plates. The steam from each group is collected overhead in a receiver, 4 feet in diameter, 10¾ feet long, of $^{7}/_{16}$-inch plate. The heating surface of each boiler is 600 square feet; grate-area 30 square feet. The working pressure is 90 lbs. per square inch; the test pressure was 180 lbs. The special feature of these boilers is the receptacle at the lower part for trapping sediment from the feed-water.

	Tons.
Weight of six boilers, with water	50
Do. two pairs of engines	120
Do. two paddle-wheels	40
Total weight	210

The normal speed of the engines is at the rate of 30 turns, or 300 feet of piston, per minute. The speed varies according to the cargo and number of flats being towed.

CHAPTER XCVII.—CHANNEL STEAMERS.

THE CALAIS-DOUVRES.

The recently introduced steamers for the cross-channel traffic are typified by the latest of them, the Calais-Douvres paddle steamer, the property of the London, Chatham, and Dover Railway Company, started in June, 1889, on regular duty between Dover and Calais. The steamer was built and engined by the Fairfield Shipbuilding and Engineering Company, Govan, Glasgow. The following are dimensions and quantities of the Calais-Douvres, and the sister vessels the Victoria and the Empress on the same service; and, for comparison, those of the Paris and the Rouen, in the service of the London, Brighton, and South Coast Railway, are added:—

London, Chatham, and Dover Railway.

VESSEL.	Length.	Breadth (Beam).	Depth.	Mean Draught.	Diameters of Cylinders (Compound). First.	Diameters of Cylinders (Compound). Second.	Grate-area.	Heating Surface.
	feet.	feet.	ft. ins.	ft. ins.	inches.	inches.	sq. ft.	sq. ft.
Victoria.......... ..	309	34	12 8	8 4	58	104	324	10,624
Empress............	324	34¾	13 5	9 0	58	104	407	13,720
Calais-Douvres....	324½	36	14 0	8 6	59	106	570	13,850
London, Brighton, and South Coast Railway.								
Paris, and Rouen	250	29	15 0	8 2	46	83	287	7,386

The engines of these vessels are compounded: those of the Calais-Douvres having a 59-inch and 106-inch cylinder, with a stroke of 6 feet; having the capacity-ratio as 1 to 3.23. The engine is diagonal direct-acting receiver compound, with surface-condensers, the same in design as the engines of the Paris and the Rouen, figs. 996, 997, 998, pages 718 to 720. The cylinders work direct to the paddle-shaft. The shaft is in two independent parts, divided at the middle, one cylinder being connected to one part and the other cylinder to the other part. The respective cranks are connected together by a drag-link, by which the engines are caused to work at right angles to each other. The second cylinder is steam-jacketed. The pistons are of cast steel, dished in form, with a cast-iron junk-ring and packing rings. The junk-ring is cast with a shoe or longitudinal extension, to increase the bearing surface. The valves are worked with the bar-link gear: the eccentric sheaves of cast steel with brass liners, the forgings of steel. The shaft, rods, and other large forged work are of steel; the crank-pins and the shaft being hollow. Steam of 110 lbs. pressure is supplied

from four double-ended steel boilers, 13¼ feet in diameter, 16¼ feet long, each having three corrugated furnaces at each end, 3 feet 5 inches mean diameter; and, collectively, 2592 tubes, 2¾ inches in diameter externally, 6½ feet long. The shell-plates are ¾ inch thick, triple-riveted, lapped at the circular seams, double-butt strapped at the longitudinal seams. The collective grate-area is 570 square feet; the heating surface is 13,850 square feet, or 24.3 times the grate-area. The boilers are fitted with forced draught to a pressure of from ½ inch to ¾ inch of water; for which four fans, 6½ feet in diameter, are employed. The paddle-wheels are 18 feet in diameter, measured to the centres of pressure; and 21½ feet over the outer edges of the floats. There are nine floats in each wheel, steel plates, 12¼ feet long, 3 feet 10 inches wide, of varying thickness, so as to counterbalance the engine. For this purpose, six floats in each wheel are $1^1/_{32}$ inches thick; two floats are 1½ inches, and one is 1¾ inches thick.

The length of the voyage between Dover and Calais is 21½ knots. The average speed of the Calais-Douvres is at the rate of 19.31 knots per hour, the engines making 44.21 revolutions per minute, and developing over 6000 indicator horse-power. The estimated consumption of coal is 38 tons per trip.

Of the sister vessels, the Victoria and the Empress, on the same service, the performance of the Empress may be here quoted, in comparison with that of the Calais-Douvres on one occasion, to exemplify the gain by the employment of forced draught:—

	Forced Draught (Calais-Douvres).	Natural Draught (Empress).
Time on passage, minutes	65.9	74.2
Revolutions per minute	43.2	35.93
Knots per hour	19.57	17.45
Slip of wheels	23 per cent.	17.4 per cent.
Pressure of steam in boilers	104.9 lbs.	100.79 lbs.
Pressure of steam in receiver	25.29 „	15.18 „
Vacuum in condenser	24.9 inches.	24.17 inches.
Coal consumed per double trip, Dover to Calais and back	38 tons.	——

Showing a gain in speed of upwards of 2 knots per hour.

THE PARIS AND THE ROUEN.

The type of engines adopted for the Calais-Douvres had already been introduced for the Channel service in the sister ships Paris and Rouen, built in 1888, for the London, Brighton, and South Coast, and the Western of France Railway Companies. The ships were built and engined by the Fairfield Shipbuilding and Engineering Company. The length on the load water-line is 250 feet; breadth, moulded, 29 feet; depth, moulded, 15 feet; draught, 8 feet 2 inches; speed on trial, 19.057 knots per hour. The engines are illustrated by figs. 996, 997, and 998. The cylinders are 46 inches and 83 inches in diameter, with a stroke of 6 feet, steam-jacketed. The crank-shaft, 16 inches in diameter, is of Siemens-Martin steel; so also

The normal speed of the engines is at the rate of 30 turns, or 300 feet of piston, per minute. The speed varies according to the cargo and number of flats being towed.

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London, Chatham, and Dover Railway.

Vessel.	Length.	Breadth (Beam).	Depth.	Mean Draught.	Diameters of Cylinders (Compound). First.	Diameters of Cylinders (Compound). Second.	Grate-area.	Heating Surface.
	feet.	feet.	ft. ins.	ft. ins.	inches.	inches.	sq. ft.	sq. ft.
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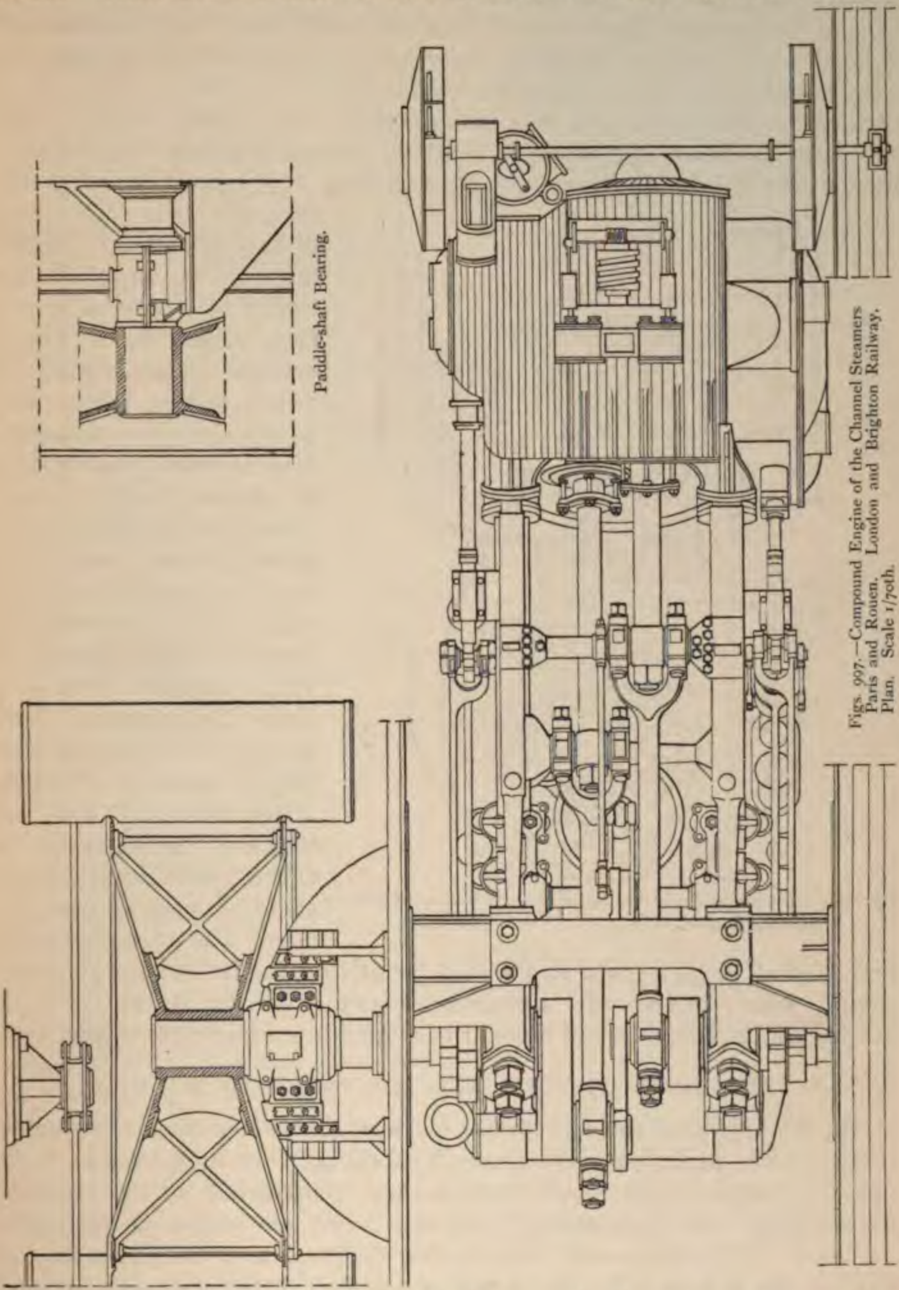
The engines of these vessels are compounded: those of the Calais-Douvres having a 59-inch and 106-inch cylinder, with a stroke of 6 feet; having the capacity-ratio as 1 to 3.23. The engine is diagonal direct-acting receiver compound, with surface-condensers, the same in design as the engines of the Paris and the Rouen, figs. 996, 997, 998, pages 718 to 720. The cylinders work direct to the paddle-shaft. The shaft is in two independent parts, divided at the middle, one cylinder being connected to one part and the other cylinder to the other part. The respective cranks are connected together by a drag-link, by which the engines are caused to work at right angles to each other. The second cylinder is steam-jacketed. The pistons are of cast steel, dished in form, with a cast-iron junk-ring and packing rings. The junk-ring is cast with a shoe or longitudinal extension, to increase the bearing surface. The valves are worked with the bar-link gear: the eccentric sheaves of cast steel with brass liners, th steel. The shaft, rods, and other large forged work are of pins and the shaft being hollow. Steam of 110 lbs. pr

wheels are feathering, 17 feet in diameter, measured to the axis of the floats. There are nine floats in each wheel, of Siemens-Martin hard-rolled



Figs. 997.—Compound Engine of the Channel Steamers Paris and Rouen. London and Brighton Railway. Plan. Scale 1/70th.

steel, curved on the driving face, with flanges at the ends, as designed by Mr. Stroudley, for the steamships Brighton and Victoria, built in 1878. The floats are 10 feet by 3 feet 7½ inches; six of these in each whe

⅞ inch thick, two are 1¼ inches, and one 1⅝ inches thick; in order to balance the engine and prevent fore-and-aft movement of the ship. Steam of 110 lbs. pressure per square inch is supplied from four multitubular boilers, two at each end of the engine-room; 13 feet in diameter, 9½ feet long, each having three corrugated furnace-tubes, of 3 feet 5 inches mean diameter. The shells are $1^1/_{16}$ inches thick. Each boiler is fitted with 318 iron flue-tubes, 2¾ inches in diameter outside, No. 9 B.W.G. in thickness, 6 feet 7½ inches long; each boiler having 71¾ square feet of grate-area, and 1842 square feet of heating surface. Forced draught is supplied by means of a pair of 6-feet fans, driven by a 7-inch cylinder steam engine, of 7-inch stroke, which exhausts into the intermediate receiver. The engines, in ordinary duty, exert about 3000 indicator horse-power. The maximum speed at which the boats have made the run between Newhaven and Dieppe, is 19¼ knots per hour, in 3 hours 20 minutes. The average time for one month was 3 hours 32 minutes. It is estimated that an indicator horse-power is effected by a consumption of 1¾ pounds of coal per hour. The gross consumption of coal, including the steam used for driving the fan-engine, steering-engine, winch-engine, and circulating-engine, with the steam used for heating cabins, &c., does not amount to 2 pounds per horse-power per hour.

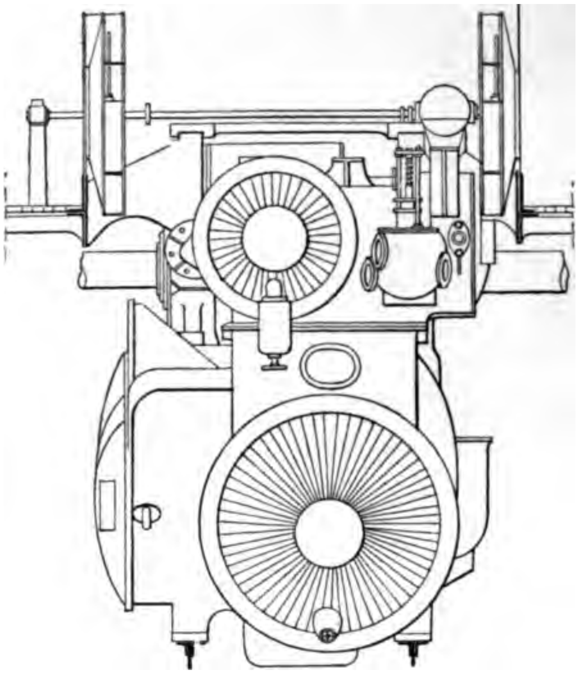


Fig. 998.—Compound Engine of the Channel Steamers Paris and Rouen. London and Brighton Railway. End View. Scale 1/70th.

THE QUEEN VICTORIA AND THE PRINCE OF WALES.

On the Liverpool and Isle of Man Channel service, the recently delivered (1889) paddle steam packets—Queen Victoria and Prince of Wales—were, like the others on the South Coast service, constructed by the Fairfield Shipbuilding and Engineering Company. But the engine is differently designed. It is compound direct-acting diagonal, and the cylinders are tandem, the first cylinder, 61 inches in diameter, being above the second cylinder, 112 inches, with a stroke of 6½ feet. They are fitted with slide-valves and the usual link-motion, with Brown's hydraulic reversing engines. The chief working parts of the engine are of steel, the paddle-shaft and

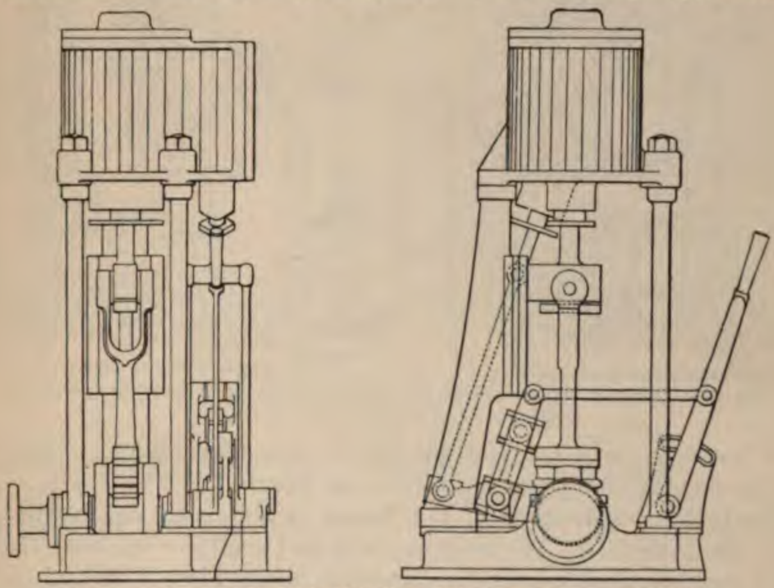
crank-pins are hollow. The paddle-wheels are feathering. Steam of 110 lbs. pressure per square inch is supplied from four double-ended boilers, 15 feet in diameter, 19½ feet long, each boiler having six furnaces of corrugated steel.

CHAPTER XCVIII.
LAUNCH ENGINES, WITH THE BREMME VALVE-GEAR.

CONSTRUCTED BY MESSRS. ROSS & DUNCAN, GLASGOW.

(Mah-Hla: single cylinder 8 inches in diameter; stroke 9 inches. Sareea: compound cylinders 10 inches and 20 inches in diameter; stroke 12 inches.)

The Mah-Hla is a composite teak and steel screw-launch, built for Messrs. Balloch Brothers, Rangoon. The vessel is 45 feet long, with 8½ feet beam, and moulded depth 4½ feet. The engine, figs. 999, is vertical,



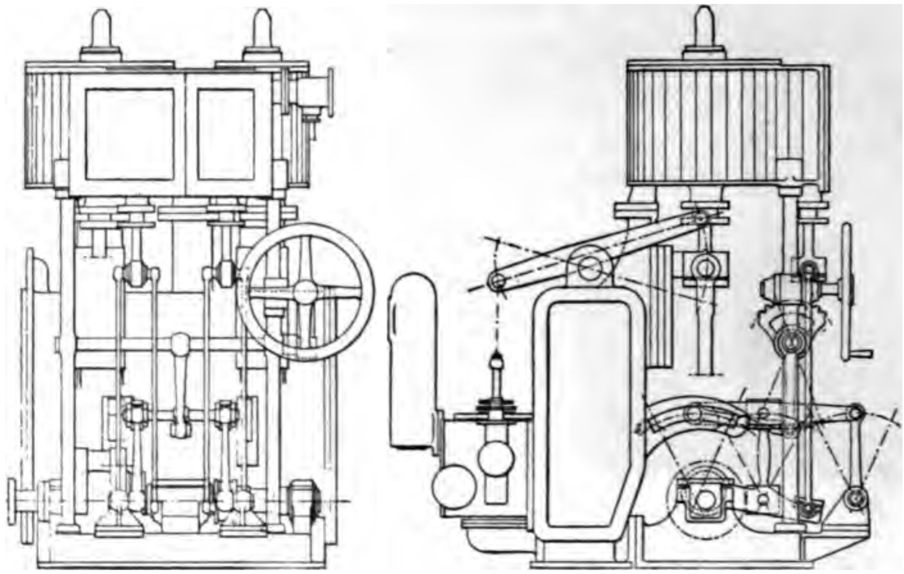
Figs. 999.—Launch Engine of the Mah-Hla, with the Bremme Gear. Scale 1/48th.

on a solid cast-iron base-plate, having a single cylinder 8 inches in diameter, with a stroke of 9 inches, non-condensing.

The engine is fitted with the Bremme valve-gear, the principle of which has already been explained, page 28. In figs. 999, the suspending link is shown in position for the beginning of the down-stroke of the engine,—coincident with the reversing arm. The normal speed of the engine, cutting off at 60 per cent of the stroke, is 260 turns, or 390 feet of piston, per minute; and that of the boat is 9 miles per hour. There is one horizontal return-tubular boiler, 5 feet in diameter, 6 feet long, having one furnace 27 inches in diameter. The working pressure in the boiler is 120 lbs. per square inch.

The Sareea screw steam-launch, with her engines, was constructed for

the service of the Egyptian government, British department. The boat is 67 feet long, with 12 feet of beam. The engine, figs. 1000, is compound, having vertical cylinders, 10 inches and 20 inches in diameter respectively, with a stroke of 12 inches, supported over a solid cast-iron base-plate. The ratio of the capacities of the cylinder is 1 to 4. Steam is cut off at 62½ per cent in the first cylinder, and 68 per cent in the second. The reversing arm is then inclined 27½ degrees from the middle position. The working pressure in the boiler is 100 lbs. per square inch, and the engine



Figs. 1000.—Compound Surface-condensing Launch Steam Engine, with Bremme Valve-gear, for the Egyptian Government Yacht Sareea. Scale 1/55th.

makes 200 turns, or a speed of 400 feet of piston, per minute. The mean speed attained by the vessel is 11 miles per hour.

The Bremme valve-gear of the Sareea is differently constructed from that of the Mah-Hla. The reversing arm and shaft are removed from the middle position, as shown in the valve-gear of the Mah-Hla; and they are placed beyond the eccentric-rod. The suspending link is pinned to a horizontal beam, one end of which is pinned to the reversing arm, and the other end is fitted with a slide-block, which moves in a fixed circular slot, having a radius equal to that of the reversing arm. To reverse the engine, the beam is shifted longitudinally by the reversing arm, and as both ends move in equal circular arcs, the middle point of connection for the suspending link likewise moves in a circular arc, and the valve-movements are the same as they would be if the link be connected directly to the reversing arm.

The condenser is surface-condensing. There are 271 tubes, ¾ inch in diameter, 3¼ feet long; making 175 square feet of condensing surface.

There is one boiler, horizontal, return-tubular, 7½ feet in diameter, 7 feet long, having two 28-inch furnace-tubes.

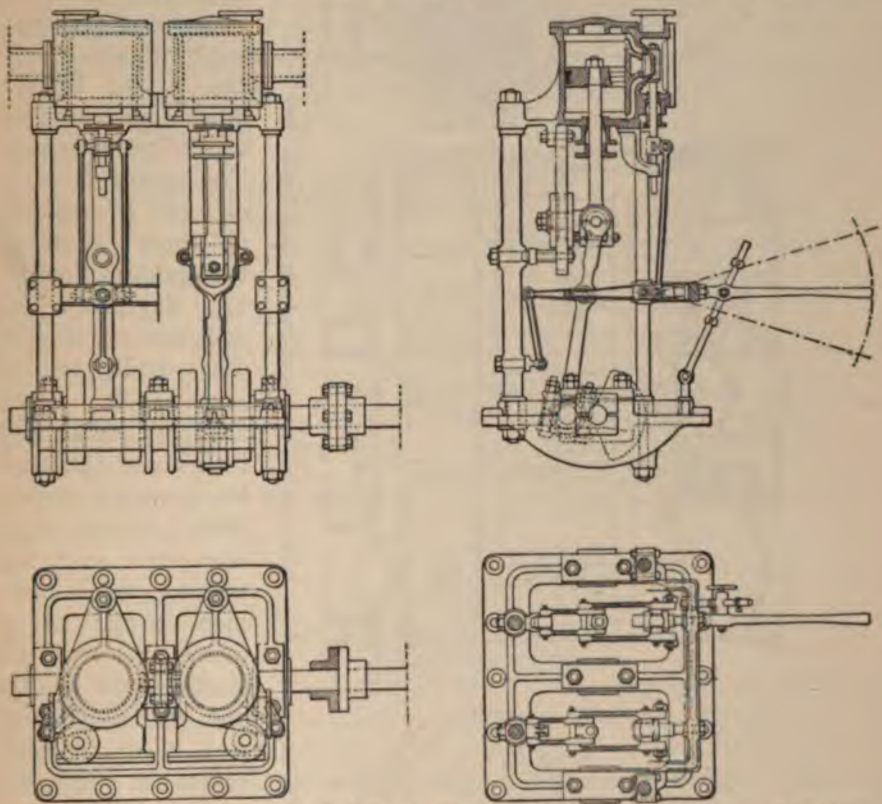
CHAPTER XCIX.

YACHT ENGINES, WITH THE JOY VALVE-GEAR.

CONSTRUCTED BY MESSRS. T. BATES & CO. (POLLIT & WIGZELL), SOWERBY BRIDGE.

(Cylinders 6½ inches in diameter; stroke 6 inches.)

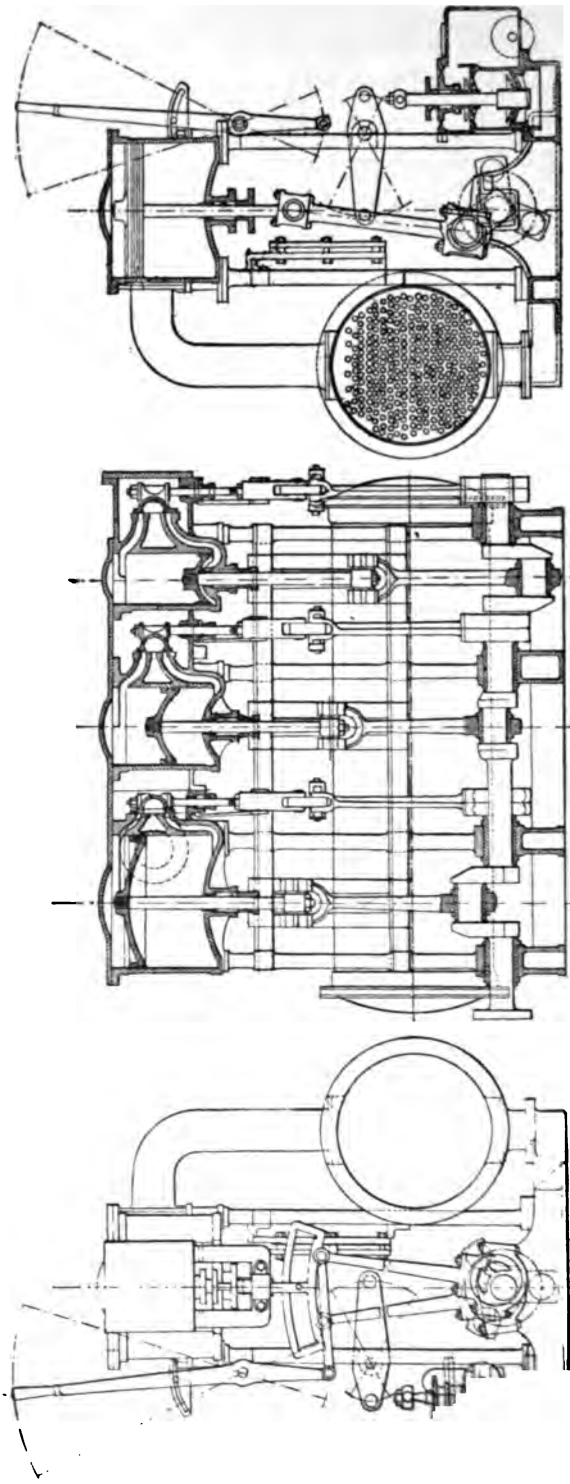
There is a pair of vertical engines, figs. 1001, having cylinders 6½ inches in diameter, with a stroke of 6 inches. The steam-ports are 5½ inches by ⅝ inch, or $^{1}/_{9.8}$ part of the cylinder-area. The engines make 250 revolutions or 250 feet of piston per minute. The crank-shaft is of cast steel, 2⅛ inches



Figs. 1001.—Yacht Steam Engine, with Joy's Gear, by Messrs. T. Bates & Co. (Pollit & Wigzell). Scale 1/20th.

in diameter, balanced by cast-iron weights fixed with wrought-iron straps. The piston is fitted with Mather & Platt's packing.

The valve has a maximum stroke of 1⅜ inches, with ¼ inch of lap, and worked by Joy's valve-gear. For the usual quadrant in which the lever-centres slide, a straight spindle with a sleeve on it is substituted. Though motion thus produced is not strictly correct, the difference made by not allowing for the versed sine of the links to the crossheads of the valve-rods is so small that it is not [illegible] ng and working of the valves, for so small an [illegible]



Figs. 1002.—Cochran & Co.: Triple-expansion Marine Steam Engine for Small Vessels. Scale 1/20th.

CHAPTER C.
TRIPLE-EXPANSION MARINE STEAM ENGINE,

ADAPTED FOR SMALL STEAM VESSELS.

This engine, figs. 1002, has been designed and constructed by Messrs. Cochran & Co., Birkenhead, adapted for small steam vessels. The engine is vertical, and is arranged on three cranks at the equidistant angles 120 degrees. The cylinders are in line, direct-acting on one crank-shaft. They are 5½ inches, 8½ inches, and 14 inches in diameter respectively; having capacity-ratios as 1, 2.4, and 6.4, with a common stroke of 8 inches. They are clothed with silicate and planished sheet steel. Ordinary slide-valves are employed, worked by link-motion gear, each cutting off at 9/16ths, or 56 per cent of the stroke. The steam-pipe is 2 inches in diameter. The crank-shaft and the crank-pins are 2⅝ inches in diameter; the piston-rods are 1¼ inches,

and the valve-spindles are ¾ inch. The air-pump is 6 inches in diameter, with a stroke of 3½ inches. The condenser is 16 inches in diameter, 4 feet 2 inches long, placed horizontally at the back of the engine. It contains 303 condensing tubes, ½ inch in diameter externally, presenting a cooling surface of 165 square feet. The feed-pumps, two in number, have 1¼-inch rams, having 3½ inches of stroke. The air-pump and feed-pumps are worked by means of levers from the crosshead of the intermediate cylinder. The circulating pump is a small centrifugal pump worked by an independent engine, having a 2-inch cylinder with a 2½-inch stroke. The inlet and outlet are of 3 inches bore. Steel is used in construction wherever feasible. The working pressure in the boiler is 160 lbs. per square inch. The engine makes 380 revolutions, or 506.7 feet of piston per minute, developing 80 indicator horse-power. The boiler is of the Cochran upright type, 5½ feet in diameter, 6½ feet long.

	tons.	cwts.	qrs.	lbs.	tons.	cwts.	qrs.	lbs.
Weight of engine	1	5	2	0				
" circulating pump	0	1	0	6				
					1	6	2	6
" boiler, empty					4	5	0	0
" " with water					6	5	0	0
" engine and boiler, empty					5	11	2	6
" do. do. full					7	11	2	6

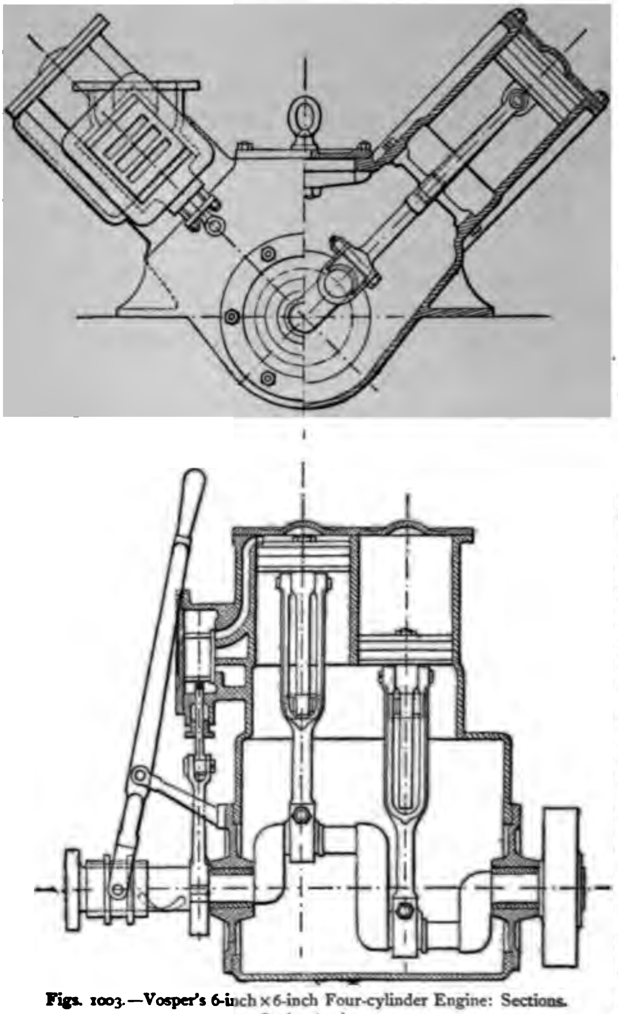
Price of engine and circulating pump	£420,	or £317	per ton.
" boiler and fittings	£390,	or £91, 15s.	"
" engine and boiler	£810,	or £145, 3s.	"

Chapter CI.—THE VOSPER FOUR-CYLINDER LAUNCH STEAM ENGINE.

The Vosper engine, figs. 1003, consists of four single-acting pistons and cylinders, arranged as two pairs, the cylinders of each pair being connected to two cranks on the shaft, diametrically opposed to each other; whilst the cylinders of one pair are at right angles to those of the other. The engine can be placed very low in the vessel, as all the cylinders are inclined upwards from the shaft.

The slide-valves of the cylinders are worked by one eccentric for all four cylinders. For the purpose of reversing, the eccentric is loose on the shaft, and is formed with a sleeve which is grooved helically on the outer surface. A clutch, under the control of a hand lever, can be shifted longitudinally on the shaft—a feather on the shaft taking into a longitudinal slot in the clutch. The clutch has a short feather which takes into the helical groove in the sleeve; and, consequently, when the clutch is shifted by means of the lever, the eccentric is caused to revolve on the shaft to an extent sufficient for working the engine reversely.

The cylinders of the engine are 6 inches in diameter, with a 6-inch stroke; making 800 revolutions, or 800 feet of piston per minute. The weight of the engine is 560 pounds.



Figs. 1003.—Vosper's 6-inch × 6-inch Four-cylinder Engine: Sections. Scale 1/12th.

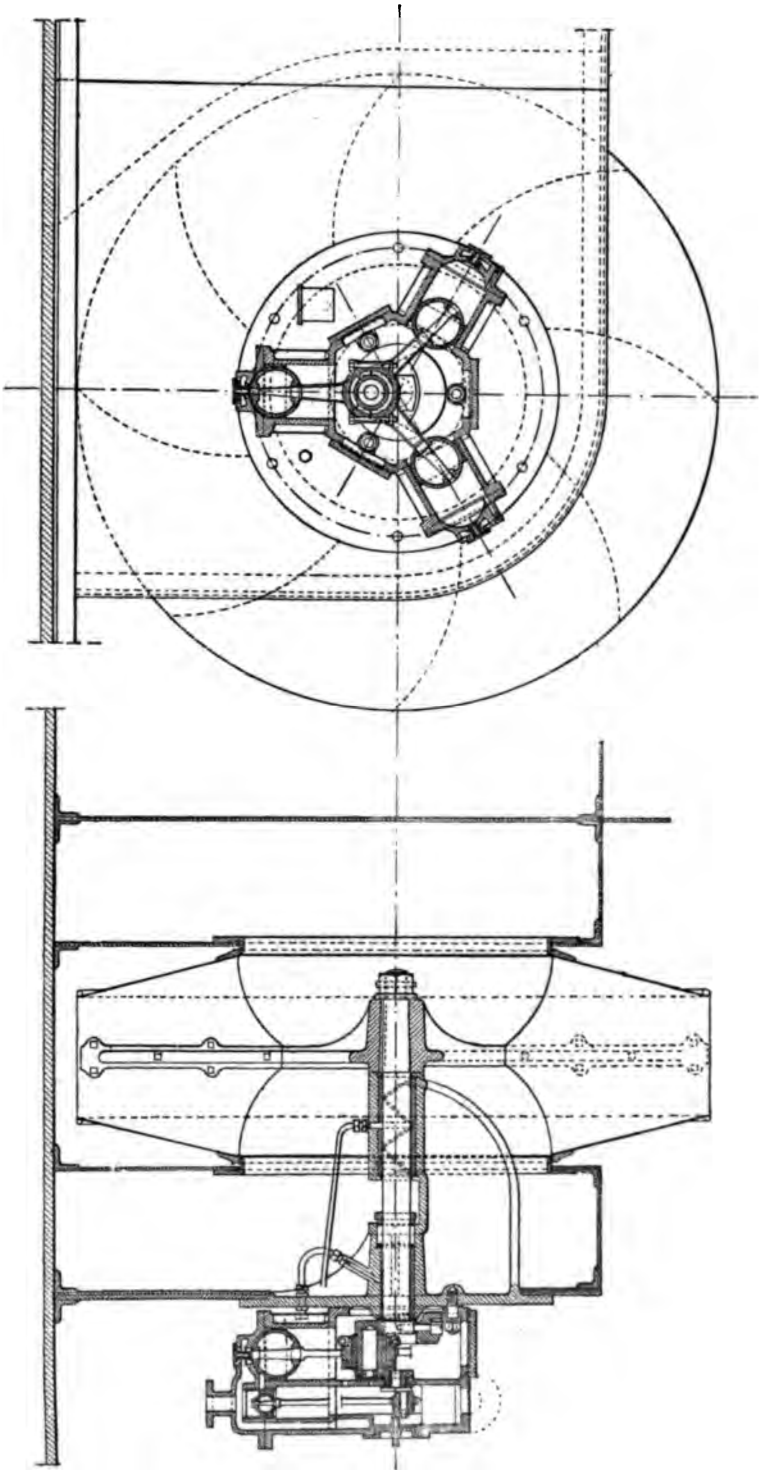
CHAPTER CII.

THE BROTHERHOOD THREE-CYLINDER ENGINES,

FOR FORCED DRAUGHT, &c.

The engines designed and constructed by Mr. Peter Brotherhood, with three single-acting cylinders, are specially adapted for high speeds of revolution. Two examples of these engines are shown by figs. 1004 and 1005. The most interesting feature is the novel construction of the pistons, which are spherical in form, and are fastened on the outer ends of the connecting-rods. They are completed with three cylindrical segments, which act as packing rings, tongued together, turned externally to the diameter of the cylinders, and bored to fit the sphere. The piston-valves are of like construction. The pistons and valves are steam-tight: the continuous pressure of the steam on the outer edges of the segments keeping them well home on the spheres, and also well up to the peripheries or walls of the cylinders.

The fan-engine, figs. 1004, is one of a set of eight, fitted on a foreign war vessel for forced draught. Running at a speed of 500 revolutions per minute, an air-pressure measured by 3 inches water-gauge is maintained in closed stokeholds. The cylinders are [illegible] hes in diameter, with a stroke of 5 inches, making a sp[illegible] 417 feet per minute.



Figs. 1004.—Peter Brotherhood's 5-inch × 5-inch Three-cylinder Engine, arranged to drive a 60-inch Fan. Scale 1/18th.

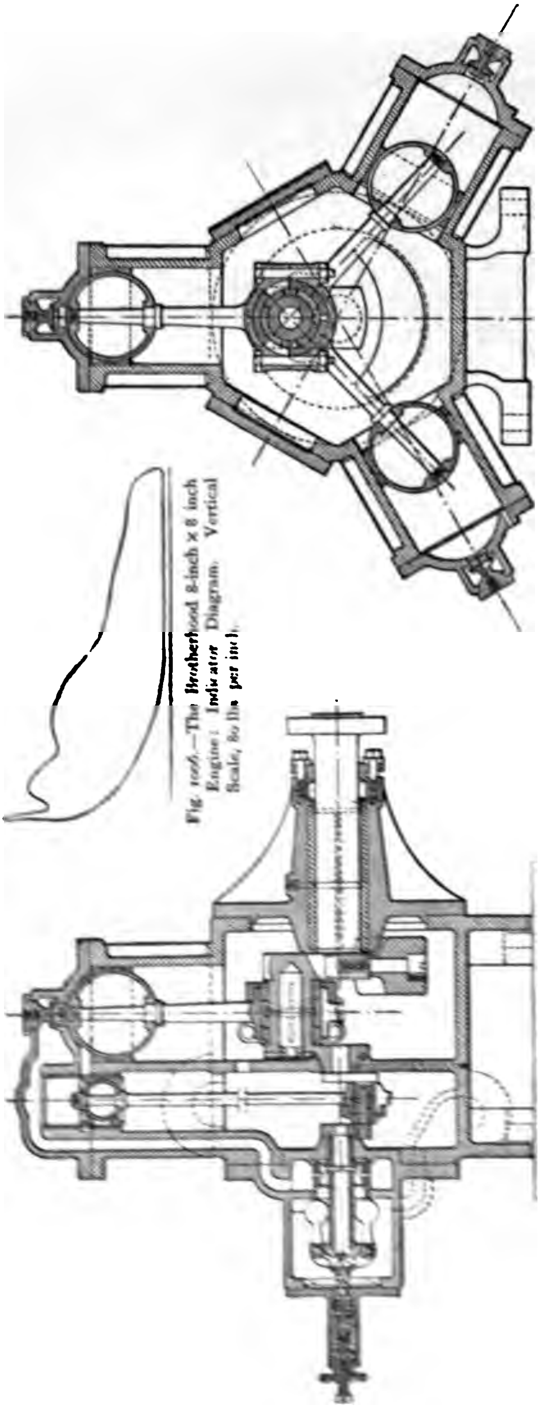


Fig. 1006.—The Brotherhood 8-inch × 8 inch Engine: Indicator Diagram. Vertical Scale, 80 lbs per inch.

Figs. 1005. Peter Brotherhood's 6-inch × 6-inch Three-cylinder Engine. Scale 1/12th.

Engines and fans of the same size are employed on the Renown, &c., by Humphreys, Tennant, & Co., as indicated in Plate XVIII. Like engines are employed by several other leading manufacturers of marine engines.

Another application of the Brotherhood engine, shown by figs. 1005, having 6-inch cylinders, of 6 inches stroke—is that of a direct-driving electric-light engine. Running at 600 revolutions, or 600 feet of piston per minute, this engine yields 20 indicator horse-power. It is fitted with a ball-governor on the shaft.

The indicator diagram, fig. 1006, was taken from an engine having 8-inch cylinders, with 8 inches of stroke, driving a dynamo at a speed of 475 revolutions per minute; and indicating 41 horse-power, with a pressure of 84 lbs. per square inch in the boiler, and 60 lbs. at the valve chest. Steam was consumed at the rate of [illegible] pounds per horse-power per hour. There is sufficient back pressure on the exhaust or return stroke, as is shown on the indicator diagram, to keep the pistons and connecting-rods home on the crank journals.

CHAPTER CIII.—DUNLOP'S COMBINED STEAM AND PNEUMATIC GOVERNOR FOR MARINE ENGINES.

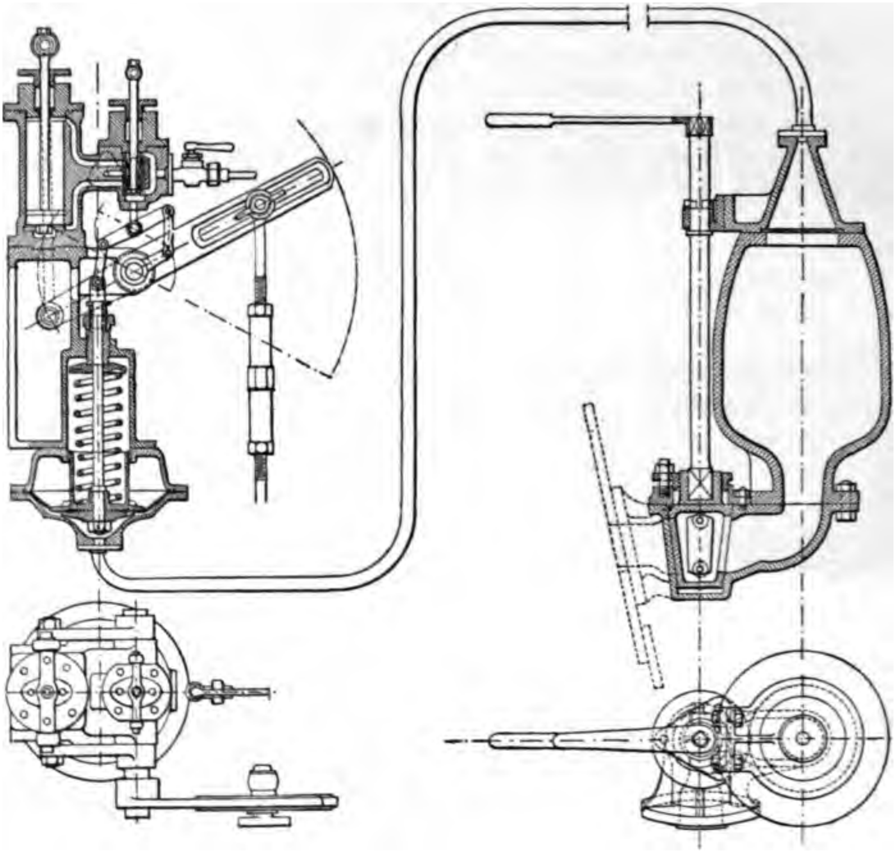
A small air-vessel is placed as far aft in the ship as possible, connected to a sea-cock, below it, through which sea-water can be admitted. The top of the air-vessel is connected by a pipe laid along the screw-shaft tunnel to a throttle-valve controlling apparatus in the engine-room, as shown in figs. 1007. An elastic diaphragm is fixed air-tight between the flanges of a circular chamber forming the lower part of the apparatus. The central portion of the diaphragm is fixed to the base of a cylindrical case, in which a helical spring is deposited, and to the bottom of which a central spindle is fastened, passing up within and through the spring. On the upper end of the spring a flat plate is supported, through which, by the action of an adjusting screw, the spring may be compressed to the required extent.

When the sea-cock is opened, the air contained in the air-vessel and piping is compressed under the head of water in which the propeller is revolving; and if the spring is screwed into a position in which the head of pressure is balanced by its resistance, the spindle remains inactive so long as a uniform draught of water is maintained. But when the stern rises, in consequence of the pitching of the vessel, the air-pressure is diminished, and the spring expands and so draws down the spindle. The upper end of the spindle, being connected by a system of links to the slide-valve of a steam cylinder, opens the steam passage to the upper end of the cylinder, in which the steam thus admitted presses the piston downwards. Through side links the crosshead of the piston-rod is connected to a lever, through which the throttle-valve is closed in exact proportion to the immersed surface of the propeller. At the same time, by the action of the lever through links, the slide-valve is closed in a greater or less degree.

The position of the elastic diaphragm, shown in figs. 1007, is the position taken when all pressure is removed from below it, the sea-cock being shut and the drains of the air-vessel open; or when the stern of the ship lifts high enough to raise the entrance to the sea-cock to the surface of the water. In operation, the diaphragm floats between the air-pressure created by the head of water at the stern, and the balancing effect of the spring. The position of the diaphragm when the full draught of water is maintained is hard up against the stops on the upper part of the diaphragm chamber. If the head of water is increased, the diaphragm cannot be lifted further upwards. But when the air-pressure under the diaphragm becomes less than what the spring is set for, the diaphragm is immediately pressed downwards; it draws down the spindle, and through the system of lever ·ks, acts on the throttle-valve.

ct of the adjusting nut at the top of the spring chamber is to of the apparatus. In general practice, the spring i

pressed to such an extent that when the tips of the propeller rise to the surface of the water, the diaphragm floats just clear of stops. With a moderate sea and a slow rate of pitching, the steam is shut off in time to prevent the engines from racing. But if, by the nature of the sea, the



Figs. 1007.—Dunlop's Marine Engine Governor. Scale 1/16th.

pitching is very quick, it becomes necessary to provide means of acting earlier on the throttle-valve. This is the purpose of the adjusting nut. By screwing it down carefully, the attendant finds the exact point at which steam must be begun to be shut off; let it be when the propeller is 6 inches, 12 inches, or 2 feet below the surface—the throttle-valve being so closed much earlier.

ADDENDA.

I. STEAM: EQUIVALENT WEIGHT OF WATER AS EVAPORATED FROM AND AT 212° F.

Let w = the weight of water evaporated per pound of a fuel, from water supplied at the temperature t, into steam of the total heat H, measured from 32° F. Let w', t', and H', be any other corresponding values for the same expenditure of heat. Then, the total heat expended in evaporating 1 lb. of water is $H+32-t$, or $H'+32-t'$, and

$$w' = w \frac{H+32-t}{H'+32-t'} \quad \text{..............................} \quad (1)$$

Let H' be the total heat of steam generated at 212° F., or 1146 units; and $t' = 212°$ F. By substitution in formula (1), and reduction,

$$w' = w \times \frac{H+32-t}{966}, \quad \text{..............................} \quad (2)$$

in which w' is the equivalent weight of water evaporated from and at 212° F.

RULE.—*To find the equivalent weight of water evaporated from and at 212° F., when a given weight of water is supplied at a given temperature, and evaporated at a given pressure.* Find, in table No. 4, page 27, vol. i., the total heat of the steam generated at the given absolute pressure; add 32 to it, and from the sum subtract the temperature of the feed-water; divide the remainder by 966, and multiply the quotient by the given weight of water. The product is the equivalent weight of water evaporated from and at 212° F.

When the water is to be taken as evaporated at 212° F., but supplied

at $t' = 100°$ F., use the divisor 1078.
at $t' = 62°$ F., „ 1116.

II. STEAM: MOISTURE OR PRIMING.

The proportion of water or moisture in mixture with steam, whether by priming, condensation, or other cause, may be determined by blowing a quantity of the so-called or nominal steam into a vessel holding a given weight of cold water: noting the weight of steam, and the initial and final temperatures of the mixture. An addition is to be made to the initial it of water, to represent the weight of water equivalent to that of the containing the water, in terms of their respective specific heats. he specific heat of wrought iron, for instance, at .1138, the equivalent water is to that of the iron vessel inversely as the spe

or as .1138 to 1.0000; that is to say, the equivalent weight of water to be added to the water contained in the vessel is, say, one-ninth of the weight of the vessel. A corresponding addition is to be made for such portion of the apparatus as may be immersed in the water.

Let W = weight of condensing water, plus the equivalent weight of the receiver and apparatus immersed in the water.

w = weight of nominal steam discharged into the vessel under water.

$W + w$ = gross weight of mixture of nominal steam and condensing water.

H = total heat of one pound of the steam, reckoned from the temperature of the condensing water.

Hw = total heat delivered by the gross weight of nominal steam discharged, taken as dry steam.

t = initial temperature of condensing water.

t' = final " " "

s = augmentation of specific heat of water due to the rise of temperature.

L = latent heat of one pound of steam.

Lw = latent heat of steam discharged into vessel, taking it as dry steam.

P = the weight of priming or moisture in percentage of the total nominal steam.

$$\text{Then } P = 100\,\frac{Hw - [(W + w) \times (t' - t + s)]}{Lw} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

RULE.—*To determine the proportion of moisture or priming in steam.*—To the rise of temperature add the augmentation of the specific heat of water. Multiply the gross weight of nominal steam by this sum, and deduct the product from the constituent heat of the weight discharged into the vessel, taken as dry steam. Multiply the remainder by 100, and divide by the latent heat of the steam taken as dry. The quotient is the proportion of water in percentage of the gross weight of nominal steam.

If there be no remainder, the steam is taken as dry.

If, on the contrary, the product be greater than the constituent heat, the difference is evidence of superheated steam, the percentage quantity of which is found by multiplying it by 100, and dividing by the given constituent heat.

III. CALCULATION OF THE HORSE-POWER OF STEAM ENGINES.

The horse-power is calculated in terms of the effective mean pressure in the cylinder, deduced from indicator diagrams, the dimensions of the engine, and the speed.

Let d = diameter of cylinder, in inches.

L = length of stroke, in feet.

p = effective mean pressure, in pounds per square inch.

r = speed in revolutions per minute.

The indicator horse-power is equal to

$$\frac{.7854\,d^2 \times L \times 2 \times p \times r}{33000};$$

or, by reduction,

$$\text{Indicator horse-power} = \frac{d^2 l p'' r}{21{,}000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Break horse-power is calculated in terms of the resultant resisting force, and its radial distance from the centre of revolution.

Let f = the resultant resisting force, in pounds.
R = radial distance, in feet.

The break horse-power is equal to

$$\frac{2\,R \times 3.1416 \times f \times r}{33000};$$

or, by reduction,

$$\text{Break horse-power} = \frac{Rfr}{5252} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

IV. PERIODS OF ADMISSION, OR CUT-OFF, FOR VARIOUS LAP AND TRAVEL OF SLIDE-VALVES.

In table No. 191 are given the periods of admission corresponding to travels of valve of from 12 inches to 2 inches, and laps of from 2 inches to ⅜ inch, with ¼ inch and ⅛ inch of lead, calculated by Rule 2, page 26, vol. ii. With greater leads than those tabulated, the steam would be cut off earlier than as shown in the table.

The influence of a lead of 5/16 inch for travels of from 1⅝ inches to 6 inches, and laps of from ½ inch to 1½ inches, as calculated for in table No. 192, is exhibited by comparison of the periods of admission in the table, for the same lap and travel. The greater lead shortens the period of admission, and increases the range for expansive working.

Table No. 191.—Periods of Admission, or Points of Cut-off, for Given Travels and Laps of Slide-valves.

Travel of Valve.	Lead.	Periods of Admission, or Points of Cut-off, for the following Laps of Valves in inches:—									
		2	1¾	1½	1¼	1	⅞	¾	⅝	½	⅜
inches.	inch.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
12	¼	88	90	93	95	96	97	98	98	99	99
10	¼	82	87	89	92	95	96	97	98	98	99
8	¼	72	78	84	88	92	94	95	96	98	98
6	¼	50	62	71	79	86	89	91	94	96	97
5½	⅛	43	56	68	77	85	88	91	94	96	97
5	⅛	32	47	61	72	82	86	89	92	95	97
4½	⅛	14	35	51	66	78	83	87	90	94	96
4	⅛	—	17	39	57	72	78	83	88	92	95
3½	⅛	—	—	20	44	63	71	79	84	90	94
-	1/16	—	—	—	23	50	61	71	79	86	91
			—	—	—	27	43	57	70	80	88
			—	—	—	—	—	33	52	70	81

Table No. 192.—Periods of Admission, or Points of Cut-off, for Given Travels and Laps of Slide-valves.

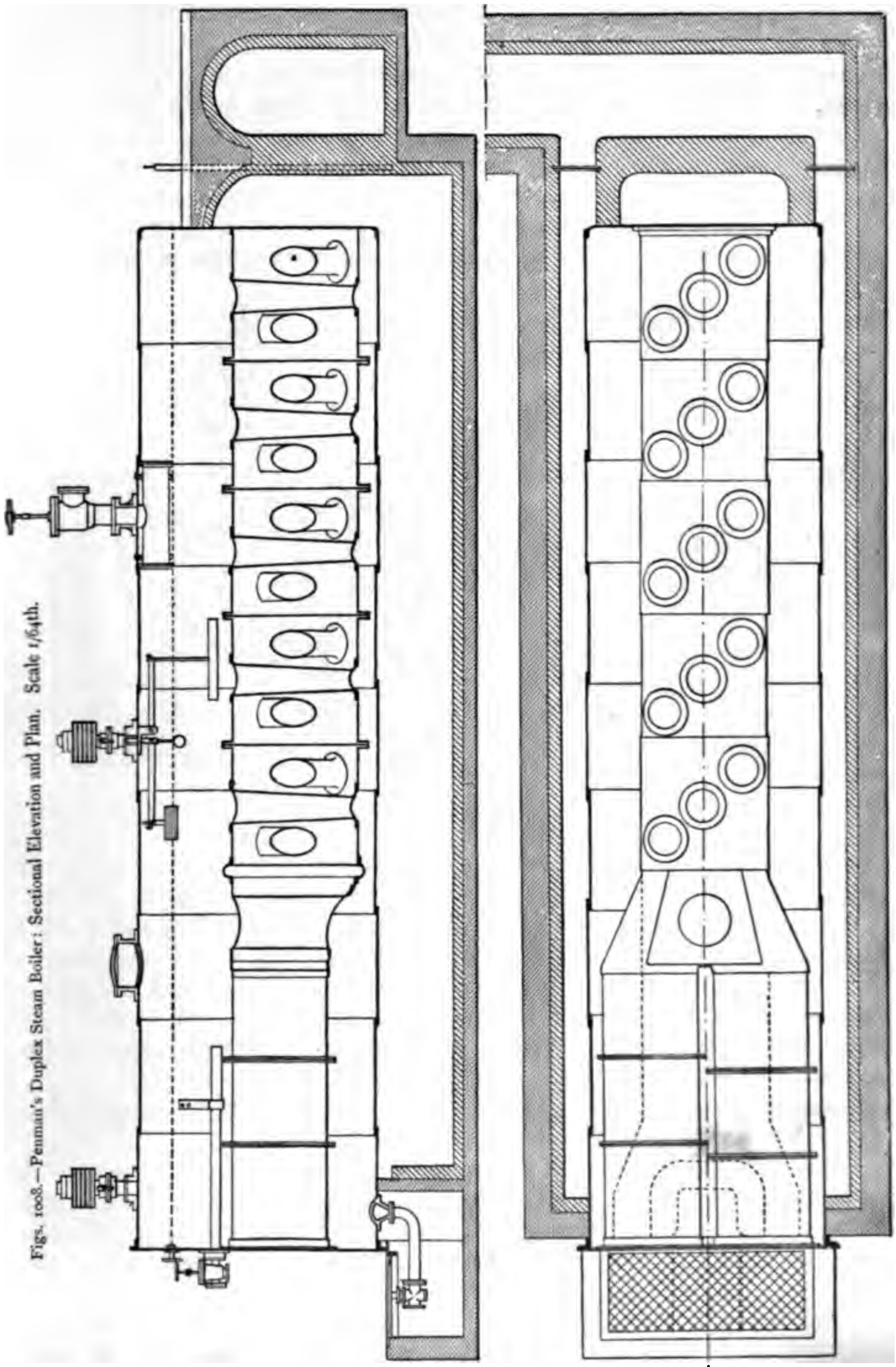
Constant Lead, 5/16 inch.

Travel.	Lap.								
Inches.	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½
1⅝	19								
1¾	39								
1⅞	47	17							
2	55	34							
2⅛	61	42	14						
2¼	65	50	30						
2⅜	68	55	38	13					
2½	71	59	45	27					
2⅝	74	63	49	36	12				
2¾	76	67	56	43	26				
2⅞	78	70	59	47	32	11			
3	80	73	62	50	38	23			
3⅛	81	74	65	55	44	30	10		
3¼	83	76	68	59	48	34	22		
3⅜	84	78	71	62	51	40	29	9	
3½	85	80	73	64	53	45	34	20	
3⅝	86	81	75	66	57	49	38	26	9
3¾	87	82	76	68	60	52	42	32	19
3⅞	87	83	78	70	63	55	46	36	25
4	88	84	79	72	66	58	49	40	29
4¼	89	86	81	76	70	63	56	47	37
4½	90	87	83	79	73	67	61	54	45
4¾	92	89	85	81	76	70	65	58	51
5	93	90	87	83	78	73	67	62	56
5½	94	92	89	86	82	78	73	68	63
6	95	93	91	88	85	82	78	74	69

V. DUPLEX FURNACE STEAM BOILER.

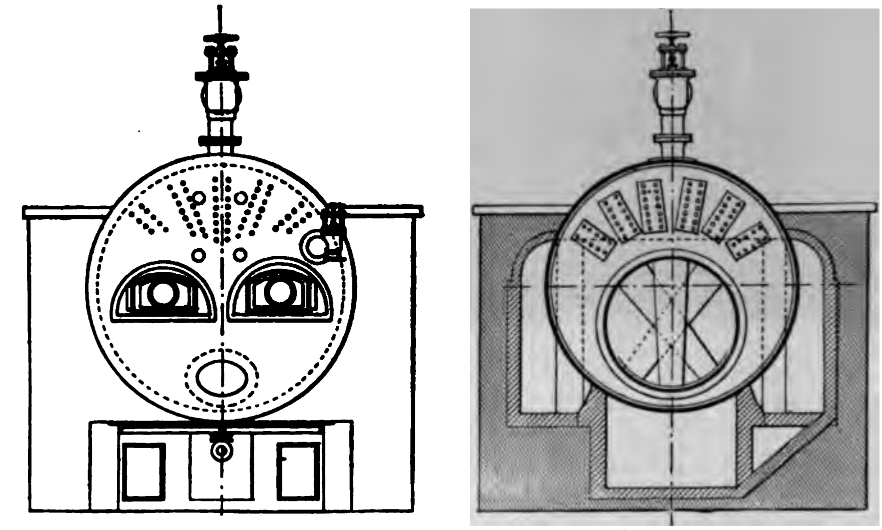
CONSTRUCTED BY MESSRS. PENMAN & CO., GLASGOW.

This boiler, figs. 1008 and 1009, based on the old "breeches" boiler, consists of a cylindrical shell, and two short furnace-tubes, joining to a single through flue-tube, combining the double furnace of the Lancashire boiler with the single flue-tube of the Cornish boiler. The boiler is of mild selected steel plates. The shell is 7 feet in diameter, 30 feet long, ½ inch thick; except the ends, of ⅝-inch plate. The edges of the plates are planed. The front end-plate is joined to the shell by means of a solid-welded 3½-inch angle steel ring, ⅝ inch thick. The back end-plate is flanged, and joined to the shell internally. The longitudinal seams are butt-jointed, with double welts, and four rows of rivets double-riveted. The furnace-tubes are 2¾ feet in diameter, 8 feet long, in two rings of 7/16-inch plate, with flanged circular seams. The combustion-chamber or junction-piece is of



Figs. 1008.—Penman's Duplex Steam Boiler: Sectional Elevation and Plan. Scale 1/64th.

$^7/_{16}$-inch plate, with a vertical junction-tube. The flue-tube is 3¾ feet in diameter, of $^7/_{16}$-inch plates, fitted with fifteen Galloway tubes, 10⅝ inches in diameter at the upper ends, 5⅝ inches at the lower ends, outside measure. The end-plates are each one piece, turned at the outer edge; stayed by gusset plates and double angle-steel, to the shell. There is one large cast-iron manhole on the top of the boiler, and a smaller one on the front plate, near the bottom; faced over the outer flanges and riveted to the boiler; with cast-iron covers and suitable bolts. Stand-pipes are riveted to the boiler, faced on the upper surface for connections of valves and



Front Elevation. Cross Section.

Figs. 1009.—Penman's Duplex Steam Boiler. Scale 1/64th.

cocks. A fusible plug is screwed into the crown of each furnace-tube. It consists of a conical seat, supporting a covering disc, 3 inches in diameter, which is perforated with small holes, filled with special metal, and is held in place by a cross bar. The fire-grates are 6 feet long, each in two lengths of 3 feet fire-bars. The fire-bars are ⅝ inch thick, with ⅜-inch air-spaces; they take a square bearing at one end, and a bevelled bearing at the other end. The boiler is tested by water-pressure to 150 lbs. per square inch, for a regular working pressure of 100 lbs. per square inch.

A 2½-inch check feed-valve is provided; also a 6-inch steam stop-valve, with a 6-inch pipe for one boiler.

There are 33 square feet of fire-grate; 952 square feet of heating surface, or 29 times the grate-area. The draught passes through the flue, returns along the bottom, and by split flue along the sides to the chimney. The top of each bridge is from 10 inches to 12 inches below the crown of the furnace.

The boiler weighs 16 tons, or with fittings 18¾ tons. The price delivered in Glasgow is £415, or £22 per ton gross. The cost of brick seating for one boiler is £50; or for six boilers £250.

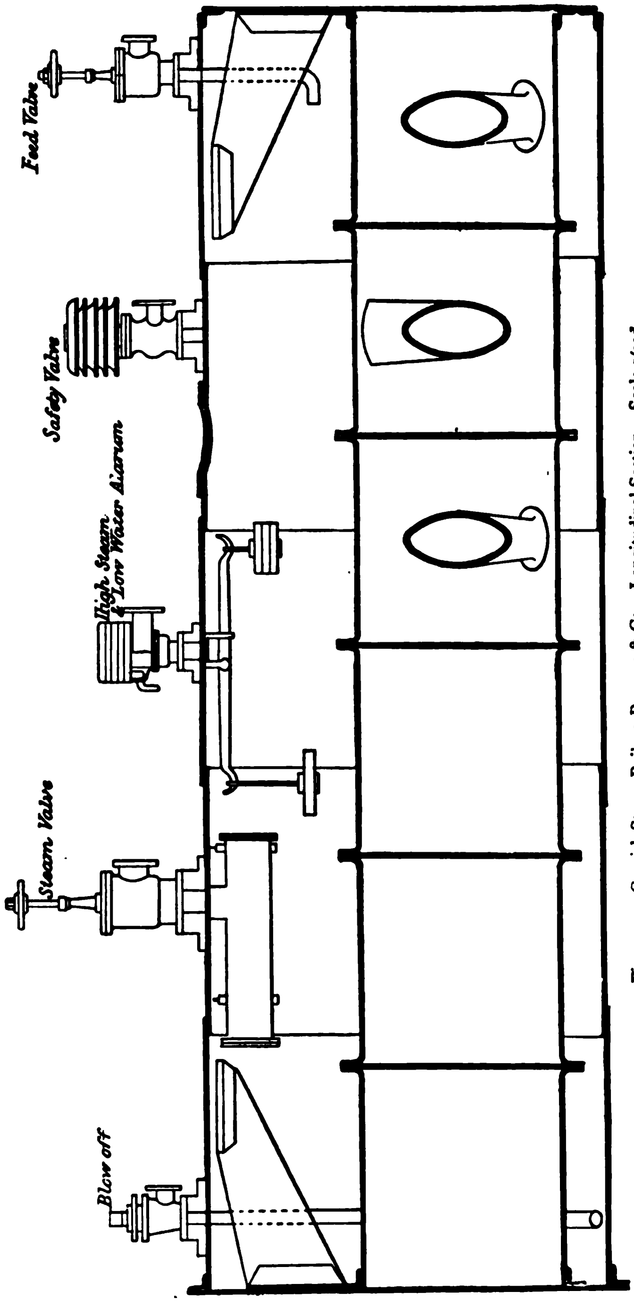


Fig. 1010.—Cornish Steam Boiler: Penman & Co. Longitudinal Section. Scale 1/32d.

VI. CORNISH STEAM BOILER.

CONSTRUCTED BY MESSRS. PENMAN & CO., GLASGOW.

This boiler, figs. 1010 and 1011, is 5½ feet in diameter, 18 feet long, of

15/32-inch steel plates, with one furnace-tube 2¾ feet in diameter, of 13/32-inch plates, with three Galloway tubes. The ends are 9/16 inch thick. The working pressure is 100 lbs. per square inch. The fire-grate is 5 feet long, and has 14 square feet of area. The heating surface is 380 square feet, or

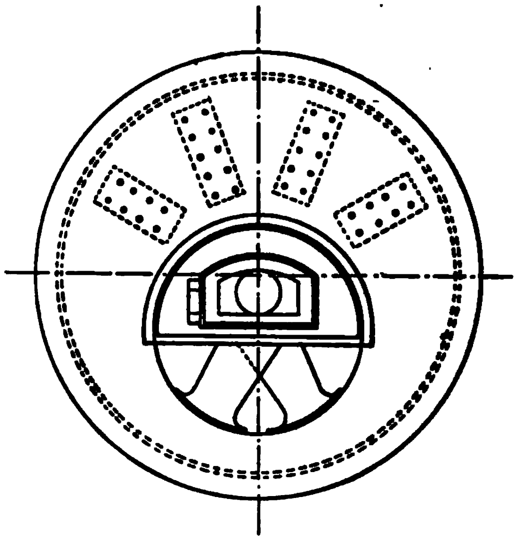


Fig. 1011.—Penman's Cornish Boiler: Front Elevation. Scale 1/32d.

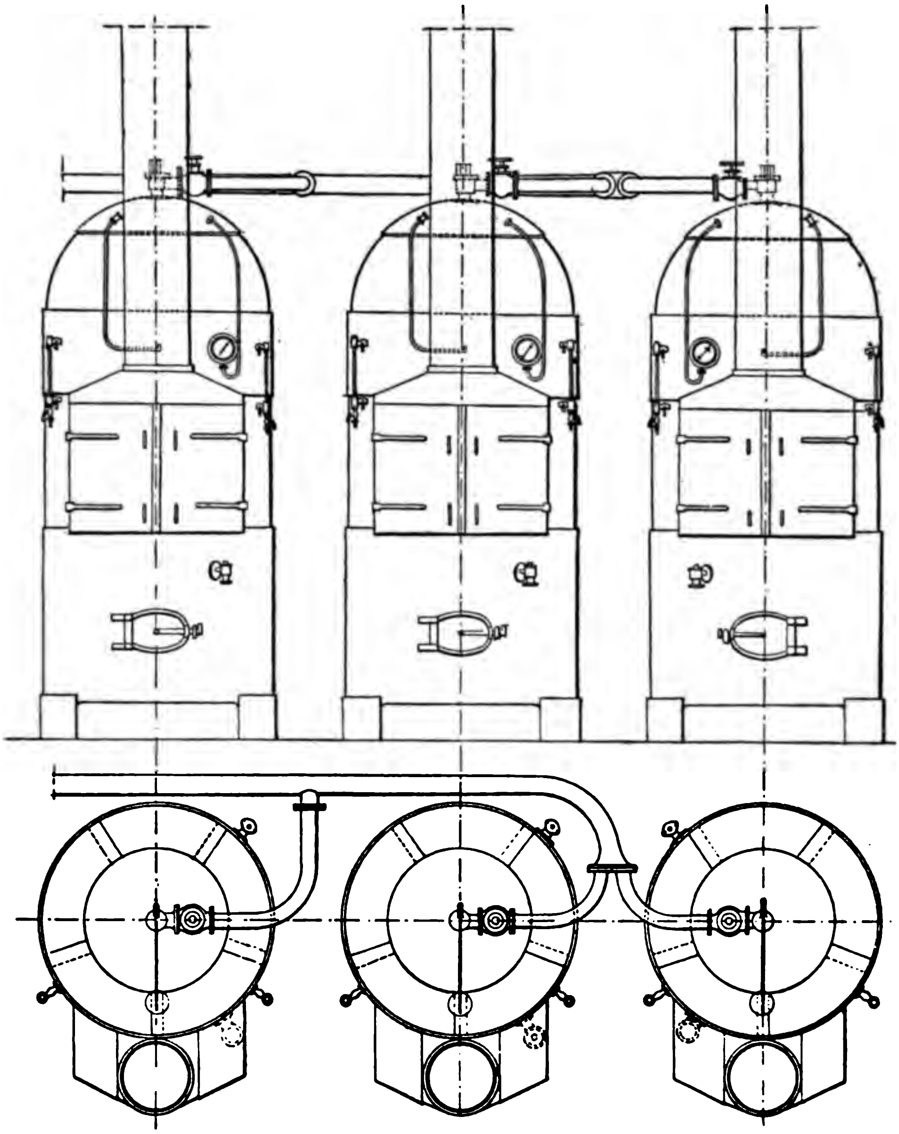
27 times the grate-area. The steam-pipe for one boiler is 4 inches in diameter; for six boilers it would be 7 inches in diameter. The weight of the boiler is 5½ tons; with mountings 7 tons 3 cwts. The price of the boiler with mountings is £199, or £28 per ton gross.

VII. THE COCHRAN STEAM BOILER IN SETS OR BATTERIES.

The Cochran boiler has been described, page 744, &c., vol. i., as a vertical multitubular boiler with horizontal flue-tubes. It has been found convenient, in cases where a great quantity of steam is required, to arrange these boilers in sets, as illustrated in figs. 1012, which represents the arrangement of three Cochran boilers at the brass and copper works of Mr. Samuel Walker, Birmingham, which have replaced other boilers of the sectional water-tube type, and are employed in supplying steam for driving hydraulic pumping engines and other purposes. They are of the standard size recommended for use in sets. Each boiler is 6½ feet in diameter, 14½ feet high; having 20½ square feet of grate-area, and 500 square feet of heating surface, or 24.4 times the grate-area. The working pressure is 100 lbs. per square inch; and each boiler is capable of evaporating 50 cubic feet of water per hour.

There is obviously a great economy of space occupied by these boilers, compared with Lancashire boilers; and a great advantage in ease and

cheapness of fixing. No brickwork setting is required, and the boilers are entirely open for examination.

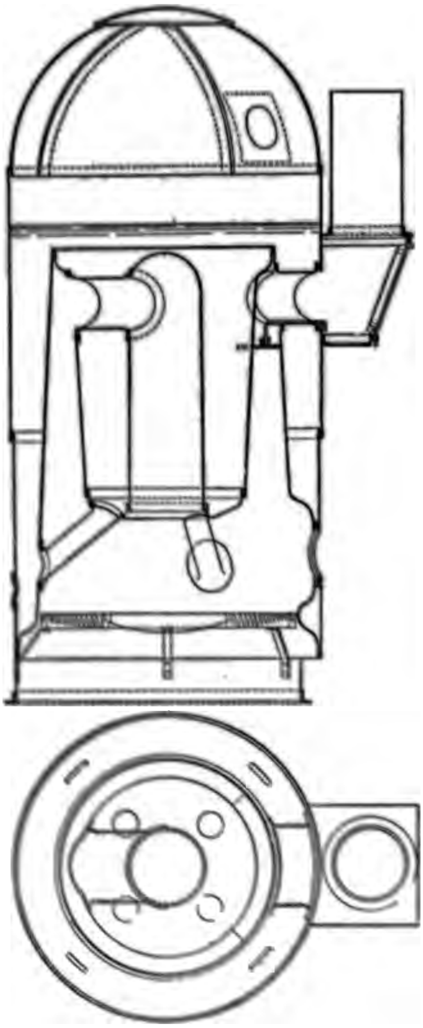


Figs. 1012.—The Cochran Steam Boiler in Sets or Batteries. Scale 1/64th.

VIII. THE BUCKLAND VERTICAL STEAM BOILER.

The vertical boiler, figs. 1013, designed by Mr. H. B. Buckland, Newcastle-on-Tyne, is cylindrical, the top of which is segmental for the smaller boilers, and hemispherical in the larger, as shown in the figure. The fire-box is

of the ordinary form used for cross-tube boilers: set out from 3 inches to 5 inches at the base to join the shell, and the sides tapering upwards at the rate of about 1 in 16. Instead of a crown plate, an inverted taper box is riveted to the upper edge of the fire-box, open to the water at the top, depending to within about 2 feet from the fire-grate. To the lower end of this box a vertical cylinder is riveted, open to the burning gases through the lower end, and finished with a hemispherical dome at the upper end. The upper part is joined by a short cross tube to the interval between the outer and inner fire-boxes, in order to circulate the hot gases that rise to the top of the internal cylinder. From this intervallic space the burnt gases are drawn off into the uptake, smoke-box and funnel, at one side. Through three or four water-pipes connecting the lower end of the inner fire-box to the outer water-space, circulation of water is promoted. There are no stays in the boiler.



[illegible] The [illegible] Vertical Steam Boiler. Scale [illegible]

The boiler is made of steel throughout. It is 6½ feet in diameter, 14½ feet high, for a working pressure of 80 lbs. per square inch. There are 23½ square feet of fire-grate area, and 260 square feet of heating surface, or 11 times the grate-area. In ordinary working, it is stated, 15 pounds of coal are consumed per square foot of grate per hour, and 10 pounds of water are evaporated per pound of good coal.

A donkey boiler of this pattern, on a steamer, 5 feet in diameter, 12 feet high, having 13.35 square feet of fire-grate, supplies steam for two winches having 6-inch cylinders; and two others, having 7-inch cylinders. A boiler at Low Walker was tested by Mr. R. G. Nichol, in October, 1888. It was in an open yard, and uncovered. It is 4½ feet i[illegible] 10 feet high, for 100 lbs. pressure, having [illegible] square fe[illegible]face, and 10.1[illegible] square feet of grate. In the course o[illegible]ds of Stella unscreened furnace coal was c[illegible] per square foot of grate per hour; and [illegible]

water per hour; or 8.46 pounds of water per pound of coal per hour; supplied at 51° F., and boiled off under atmospheric pressure.

The price of one of these boilers, 5 feet by 12 feet, weighing, with mountings, 3 tons 19 cwts., with a donkey pump, is £175, or, say, £44 per ton.

IX. MILLS' HIGH-PRESSURE SECTIONAL STEAM BOILER.

The Mills boiler is a combination of a cylindrical water-cased furnace, with an ordinary water-tube sectional boiler, represented by figs. 1014 and 1015. The feed-water is introduced into the steam and water drum at the upper part, and circulates independently through the furnace-casing and the water-tubes.

The system, adapted to a Babcock and Wilcox boiler erected at Victoria Mills, Droylsden, has been exhaustively tested by Mr. Michael Longridge and others. But the boiler was first subjected to a series of exhaustive tests, as originally constructed and erected. It consisted of 42 pipes or tubes 16 feet long, 4 inches in diameter, and a steam and water drum 21 feet 4 inches long, 3½ feet in diameter, surmounted by a smaller drum which served as a steam dome. The standard fire-grate for this boiler is 5 feet long, 3 feet 10 inches wide, making 19 square feet. But the grate had been reduced by brickwork to 17½ square feet area for the first day's test, on the 24th April, 1889, conducted by Mr. Michael Longridge; and still further to 15.33 square feet, and 10.66 square feet, on the two following days respectively. The pressure was limited by circumstances to a maximum of 65 lbs. per square inch. The coal used was "burgy" or engine coal from the Worsley district, costing 8*s.* 9*d.* per ton delivered. The composition of the fuel, as dry, was as follows:—

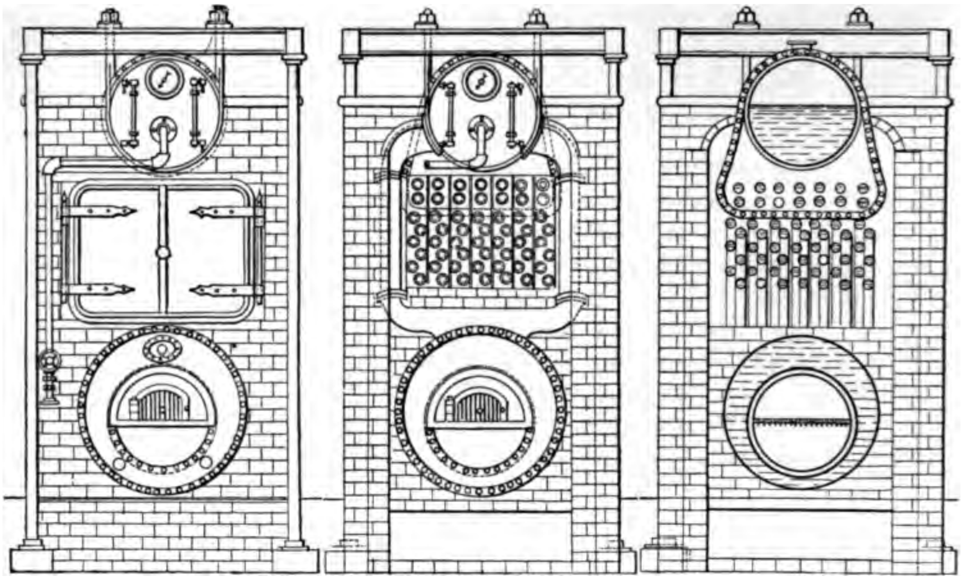
	In 100 Parts.
Carbon	77.87
Hydrogen	4.78
Oxygen	9.71
Nitrogen	1.56
Sulphur	1.91
Ash	4.17
	100.00

The calorific value, by calorimeter, was 13,360 units of heat per pound of the fuel. The composition of the burnt gases aspirated for five or six hours each day, was as follows. Mr. Longridge explains that the excessive production of carbonic oxide on the first and second days was no doubt due to an insufficient supply of air, as the draught was slow, and the slides in the fire-doors were closed:—

	First Day.	Second Day.	Third Day.
Carbonic acid	10.20	8.90	5.60
Oxygen	7.88	8.00	13.63
Carbonic oxide	1.06	1.60	.55
Nitrogen	80.86	81.50	80.22
	100.00	100.00	100.00

It was ascertained by means of simple apparatus that there was little or no priming of water with the steam.

Each day's trial lasted 7½ hours.



Figs. 1014.—Mills' High-pressure Sectional Steam Boiler. Front Elevations and Cross Section. Scale 1/75th.

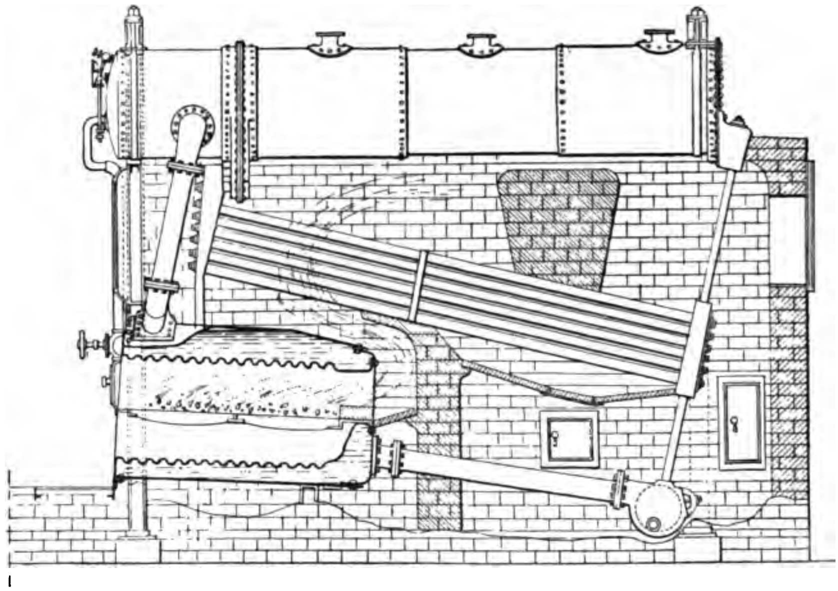


Fig. 1015.—Mills' High-pressure Sectional Steam Boiler. Longitudinal Section. Scale 1/75th.

The leading results of the three days' tests with hand-firing, are given in the first part of table No. 193. The distribution of the pot[illegible] of combustion of the fuel is given by Mr. Longridge in th[illegible] balance sheet, and is shown in table No. 194.

193.—Comparative Results of Performance of an Ordinary Water-tube Boiler, and the same Boiler having a Water-cased Furnace (Mills' System). 1889.

	Ordinary Water-tube Boiler.				Combined Water-tube Boiler and Water-cased Furnace.				
No. of Test	1 A.	2 A.	3 A.	Averages. A.	1 B.	2 B.	3 B.	4 B.	Averages. B.
Heating surface ... sq. ft.	863	863	863	863	850	840	828	825	831
Grate-area ... " "	17.50	15.33	10.66	14.49	18.6	15.13	11.3	10.3	13.83
Temperature of chimney gases ... Fahr.	476°	434°	449°	453°	424°	401°	407°	394°	300°
Do. feed-water ... "	180°	180°	174°	178°	173°	169°	169°	169°	169°
Working pressure of steam ... lbs.	62	61	60	61	60	59	58	59	59
Water evaporated per hour ... "	2684	2393	1844	2307	3697	2809	2533	2500	2885
Coal consumed per hour ... "	427	371	271	356.3	410.6	302.6	271	250	308.5
Ash ... per cent.	12.1	12	8.3	10.8	5.19	8.44	7.6	7.01	7.06
Calorific value of 1 lb. of dry coal ... heat units.	13,360	13,360	13,360	13,360	13,363	13,725	13,845	13,845	13,694
For relative utility, showing heat transferred to one pound of water ... "	6729	6909	7326	6985	9566	10,035	10,438	10,892	10,233
Coal per square foot of heating surface per hour ... lbs.	.49	.43	.31	.41	.48	.36	.32	.34	.37
Coal per square foot of fire-grate per hour ... "	24.4	24.2	25.5	24.7	22.1	20.3	22.6	22.5	21.9
Water evaporated per pound of coal ... "	6.28	6.44	6.79	6.5	9.0	9.3	9.7	10.0	9.5
Do. do. do. as from and at 212° F. ... "	6.70	6.86	7.27	6.95	9.68	10.0	10.43	10.74	10.21
Weight of dry coal per hour ... "	410	356	260	342	391	283	245	232	288
Water evaporated per lb. of dry coal ... "	6.546	6.721	7.092	6.78	9.45	9.92	10.33	10.77	10.12
Do. do. do. as from and at 212° F. ... "	6.93	7.12	7.58	7.20	10.17	10.51	11.08	11.57	10.83

Note to Table.—Tests 1 B, 2 B, and 3 B of the second part of the table, are averages of 8 single tests.

Table No. 194.—Distribution of the Potential Heat of Combustion of Fuel in a Water-tube Boiler (Balance Sheet).

	First Trial.		Second Trial.		Third Trial.	
Dr.						
To value of 1 lb. of dry fuel.....	13,360 units.		13,360 units.		13,360 units.	
„ heat contained in fuel........	3 „		3 „		4 „	
„ heat contained in air.........	44 „		47 „		114 „	
	13,407 „		13,410 „		13,478 „	
Cr.	units.	per cent.	units.	per cent.	units.	per cent.
By heat transferred to water	6729	50.18	6909	51.52	7326	54.36
„ heat lost in products of combustion........ 1129			1092		1136	
„ heat lost in excess air... 579			573		1861	
„ heat lost in evaporating and superheating water in coal.................... 51	1759	13.13	51 1716	12.79	51 3048	22.61
„ heat lost by imperfect combustion	656	4.89	1070	7.98	656	4.87
„ heat lost in unburnt carbon falling through grate, and drawn out of furnace with ashes.........................	1226	9.14	1203	8.97	659	4.89
„ heat lost in clinker...........	40	.31	39	.30	27	.20
	10,410		10,937		11,716	
„ Remainder, including radiation and transmission through brickwork	2997	22.35	2473	18.44	1762	13.07
	13,407	100.00	13,410	100.00	13,478	100.00

According to these results, from 13 per cent to 22 per cent of the total heat of combustion was dissipated through the brickwork surrounding the furnace and the front doors. The external surface of the structure measured about 840 square feet. The front consisted mainly of cast iron lined with brickwork; the sides and back were of 18-inch brickwork. Though the boiler was under shelter, yet the air was free to circulate about the structure. In this connection it may be stated that steam was got up each morning between 6.30 and 7 A.M., in order to warm the brickwork thoroughly before the commencement of the trial. The test was begun at 9 A.M.

More lately, the ordinary brick-lined furnace of the Babcock & Wilcox boiler was replaced by a short cylindrical water-cased furnace, on Mr. Mills' system, internally fired, and the boiler thus modified was again submitted for exhaustive trial by Mr. Michael Longridge, as well as by others. water-cased furnace was $8\frac{1}{4}$ feet long, 5 feet in diameter, having an corrugated tube 3 feet $1\frac{1}{2}$ inches in diameter, set with a sli downward from the front. The top of the front end wa drum of the boiler overhead by a 10-inch wrought-iron end to the mud-drum by a 7-inch wrought-iron pipe

Table No. 195.—Mills' High-pressure Sectional Steam Boiler: Balance Sheet of the Total Heat of Combustion.

Dr.	Nov. 19.		Nov. 20.		Nov. 21.		Dec. 4.		Dec. 5.		Dec. 6.		Dec. 7.		Dec. 12.		Dec. 13.	
	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.	Thermal Units.	Per Cent.
To calorific value of 1 lb. of coal	13,363		13,363		13,363		13,845		13,648		13,648		13,845		13,845		13,845	
Heat contained in air and coal	84		38		51		26		20		15		28		13		47	
	13,447		13,401		13,414		13,871		13,668		13,663		13,873		13,858		13,892	
Cr.																		
By heat transferred to water	9,169	68.18	9,396	70.11	10,135	75.56	10,448	75.32	9,752	71.26	9,905	72.41	9,900	71.36	10,524	75.96	10,892	78.4
By heat lost in evaporating and superheating moisture in coal	64	0.47	64	0.48	65	0.48	66	0.48	94	0.69	96	0.70	65	0.47	79	0.57	94	0.68
By heat lost by imperfect combustion	541	4.03	379	2.83	—		434	3.13	134	0.98	370	2.71	316	2.28	—		—	
By heat lost by unburnt carbon	177	1.32	272	2.03	108	0.81	586	4.22	682	4.99	659	4.82	781	5.64	432	3.11	503	3.62
By heat lost in drawing ashes	34	.25	38	0.28	31	0.23	54	0.39	58	0.42	58	0.42	60	0.43	45	0.32	48	0.35
By heat lost in chimney gases	996	7.41	1,102	8.22	1,167	8.70	906	6.53	963	7.03	1,003	7.33	1,146	8.25	1,079	7.78	992	7.14
By heat lost in excess air	781	5.81	655	4.89	781	5.82	665	4.80	568	4.15	544	3.98	694	5.00	662	4.78	733	5.28
Remainder, including radiation and other unascertained losses	1,685	12.53	1,495	11.16	1,127	8.4	712	5.13	1,417	10.48	1,028	7.63	911	6.57	1,037	7.48	630	4.53
	13,447	100.00	13,401	100.00	13,414	100.00	13,871	100.00	13,668	100.00	13,663	100.00	13,873	100.00	13,858	100.00	13,892	100.00
Analyses of 100 cub. ft. of chimney gases.																		
Carbonic acid	9.30	...	10.20	...	10.10	...	9.6	...	10.50	...	11.10	...	8.80	...	10.43	...	9.70	
„ oxide	0.70	...	0.53	...	0.00	...	0.6	...	0.20	...	0.60	...	0.40	...	0.00	...	0.00	
Nitrogen	42.79	...	49.02	...	46.55	...	44.02	...	48.83	...	49.74	...	50.47	...	48.48	...	44.60	
Air	47.21	...	40.25	...	43.35	...	45.78	...	40.47	...	38.56	...	40.33	...	41.09	...	45.70	

the space above the back part of the tubes of the boiler was filled up with brickwork, so as to keep the gases circulating amongst the tubes. A cross wall was added, through which the front ends of the tubes projected, reaching from the furnace casing to the drum. The fire-grate was 6 feet long; but the effective length was reduced for the different trials by brickwork laid over the back part. The surface of the grate was 22 inches below the crown of the furnace.

The boiler was cleaned out internally and brushed externally a few days before the trials were begun, which took place in November and December, 1889. The coal used was burgy from Worsley, said to be of the same quality as that used in the trials of the original boiler. The composition was as follows:—

	In 100 Parts.
Carbon	76.53
Hydrogen	5.25
Oxygen	10.36
Nitrogen	1.67
Sulphur	1.54
Ash	4.65
	100.00

By calometric test, the calorific value of the coal used was 13,648 units of heat.

The trials lasted from 6 hours to 7½ hours. Average results of nine trials are given in the second part of table No. 193, page 743. The first "test," marked 1 B, is an average of the first three successive tests; the second "test," marked 2 B, is an average of the second three tests; and the third "test," marked 3 B, of the seventh and eighth tests. They show that a remarkable degree of economy was effected by the insertion of the water-cased furnace.

A balance sheet of the total heat of combustion is given in table No. 195. In the lower part of the table are given analyses of 100 cubic feet of the burnt gases, in each trial, by volume.

X. COMPARATIVE TRIALS OF THE EVAPORATIVE PERFORMANCE OF COALS IN LANCASHIRE STEAM BOILERS, AT CLEVELAND STEEL WORKS, 1888.

A long series of test trials of various descriptions of coals was conducted by Mr. Franklin Hilton, at the works of Messrs. Bolckow, Vaughan, & Co., Middlesbrough, in October and November, 1888. The boilers were of the Lancashire type, 7 feet in diameter, 30 feet long, having two furnace-tubes 2[illegible] feet in diameter, with five Galloway cross tubes in each, according to the section, fig. [illegible]. The fire-grates for hand-firing were 6 feet 2 inches long, and had [illegible] square feet area for each [illegible] surface of each boiler was [illegible] square feet, or 25 ti[illegible]-bars were [illegible] spaces [illegible] of air-

space was 840 square inches,—say 6 square feet—for one boiler. There are two chimneys, 200 feet high, above the level of the grates, 20 feet square at the bottom, inside, and 11 feet 4 inches square at the top; one chimney serving 12 boilers, and the other serving 30 boilers.

The trials were made with large and small coals or slack: Black Boy Splint, and Shildon Lodge. The fuel was charged by hand-firing, and

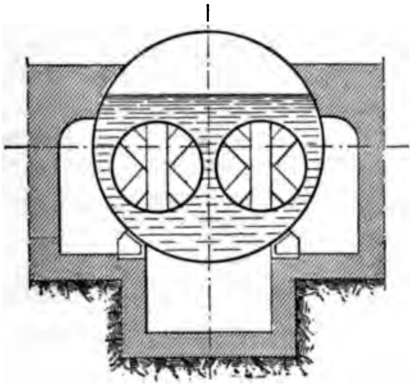


Fig. 1016.—Lancashire Boiler.

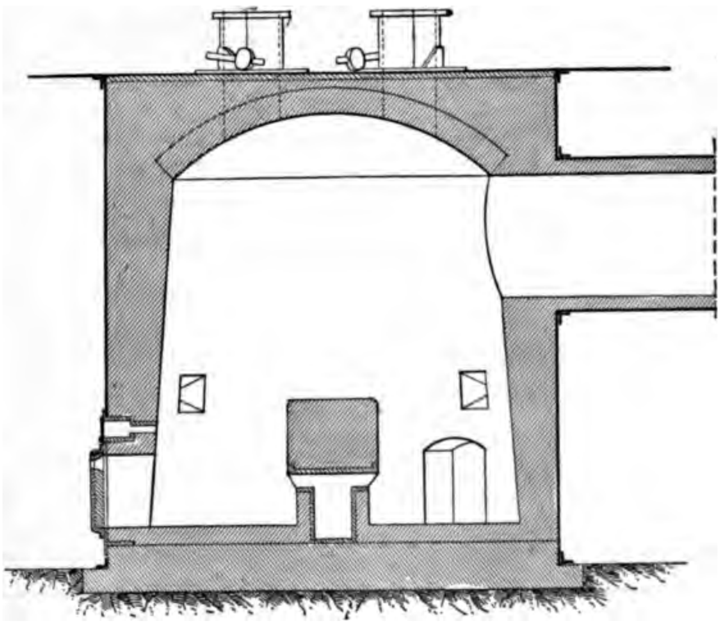


Fig. 1017.—Gas-producer.

Cleveland Steel Works: Sections of Experimental Boilers and Gas-producers.

by mechanical firing; and was also preliminarily converted into gas in producers, of which a section is shown in fig. 1017. Exteriorly, the procers were cylindrical, 14 feet in diameter, 15 feet high. Interiorly, were slightly coniform, 11½ feet in diameter at the floor, 10 feet in

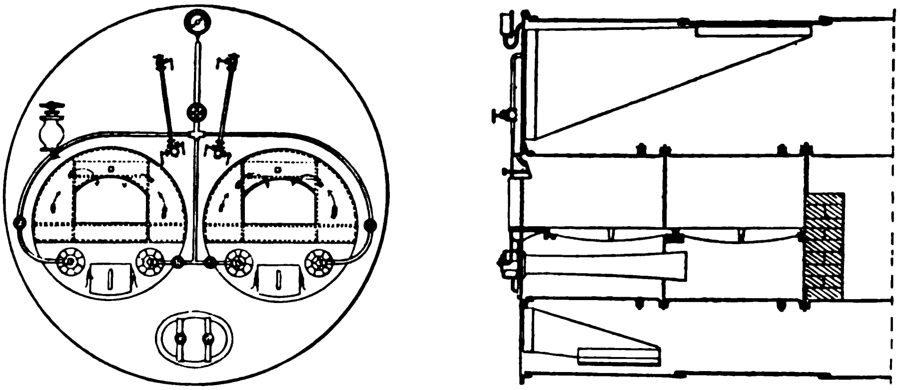
in the seventh column, determined by means of Thompson's calorimeter, affords the means of calculating the evaporative efficiency of the fuel attained in each trial.

Generally, complete combustion was effected, with a considerable proportion of free or unused air. Summarized as percentages by weight of the total quantity of discharged gases, omitting accidental extremes, the proportions of free air were as follows:—

Hand firing	17 to 35 per cent.	Average, 26 per cent.
Gas firing.....................	?	?
Bennis mechanical stoker..	42 to 53 „	„ 47 „
Proctor mechanical stoker..	24 to 38 „	„ 29 „

XI. MELDRUM'S FORCED DRAUGHT, APPLIED TO A LANCASHIRE STEAM BOILER.

According to the Meldrum system of forced draught, as applied to a Lancashire steam boiler, figs. 1018, a jet of steam from the boiler is discharged into the smaller end of a conical tube, by which steam is inducted into the ash-pit. Two blowers are shown in each ash-pit. They are formed



Figs. 1018.—Meldrum's Forced Draught, applied to a Lancashire Steam Boiler.

with inlet air-valves, for shutting off or for regulating the supply of air, or for using only one blower at a time. The furnace-front is hollow, and air from the ash-pit rises through the chamber at each side of the doorway. The air current is discharged on the surface of the fire from under a weighted flap-valve at the upper part of the chamber above the doorway. The valve closes by gravitation, and is opened to any required extent by means of a set-screw. The fire-door and its seat are faced, making a sound joint. The ashpit doors and seats are likewise faced to make tight joints; so that the fire may be forced independently of the chimney draught.

The weight of steam consumed by th rs under the best conditions is taken at 4 per cent of the total erated. It

is stated that a considerable degree of economy is effected by the employment of the blowers.

XII. ON THE INFLUENCE OF THE TEMPERATURE OF AIR SUPPLIED UNDER THE FIRE-GRATES OF STEAM BOILERS.

Messrs. Meunier and Scheurer-Kestner had obtained about 7 per cent greater evaporative efficiency in summer than in winter, from the same boilers under like conditions: an excess which had been explained by the difference of loss by radiation and conduction. But Mr. Poupardin, surmising that the gain might be due in some degree also to the greater temperature of the air in summer, made comparative trials with six new steam boilers, at the works of Messrs. Schlumberger, Sons, & Co., at Mer Rouge. An apparatus consisting of a series of cast-iron pipes, was placed vertically in the flueway towards the chimney. The upper ends were open to the air; the lower ends opened into a chamber, from which the heated air was conducted to the front of the boilers. The smoke circulated amongst the pipes as in Green's economizer. In May, 1889, two series of trials were made with two groups of three boilers, each working one week with the heated air, and the next week with cold air. The following were the several efficiencies:—

First Trials: Three Boilers; Ronchamp Coal.

	Water per lb. of Coal.	Water per lb. of Volatile Elements.
With heated air (128° F.)	7.77 lbs.	8.95 lbs.
With cold air (69°.8)	7.33 „	8.63 „
Difference in favour of heated air	0.44 „	0.32 „
Second Trials: Same Coal; Three other Boilers.		
With heated air (120°.4 F.)	8.70 lbs.	10.08 lbs.
With cold air (75°.2)	8.09 „	9.34 „
Difference in favour of heated air	0.61 „	0.64 „

These results show economies in favour of heating the air of 6 per cent and 7½ per cent. The respective average pressures of steam were 4.25 and 4.30 atmospheres in the first trials, and 4.3 and 4.26 atmospheres in the second trials. The respective quantities of coal consumed were, in the first trials, 48,180 pounds and 45,540 pounds; in the second, 44,660 pounds and 48,180 pounds.

Mr. Poupardin believes that the gain in efficiency is due chiefly to the better combustion of the gases with heated air. It was observed that with heated air the flames were much shorter and whiter, and that there was notably less smoke from the chimney.

XIII. THE DAVEY COMPENSATING COMPOUND PUMPING STEAM ENGINE.

This engine is designed as an equivalent in the principle of action to the old single-cylinder pumping engines, in which, in order to render

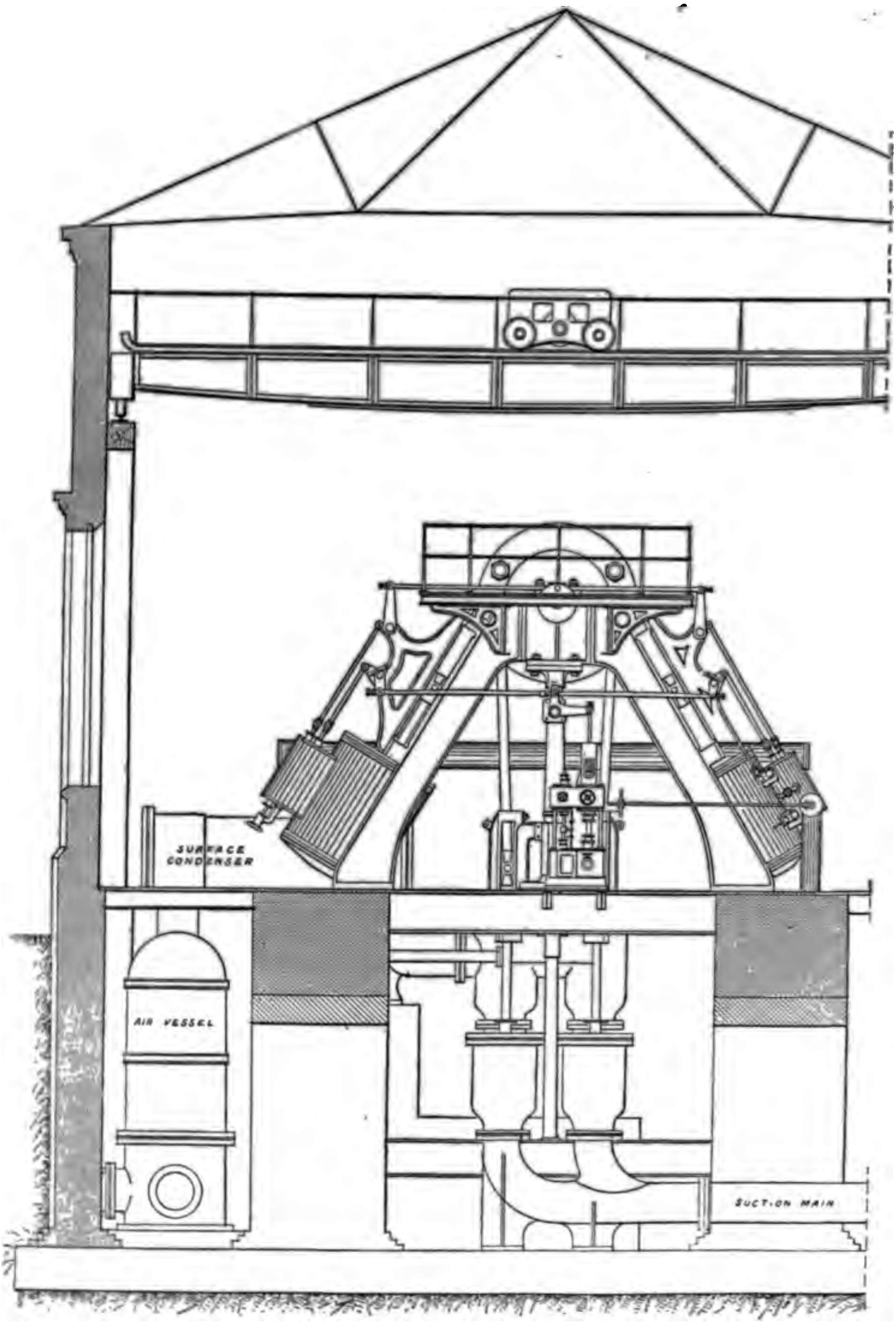


Fig. 1019.—Davey Compensating Compound Pumping Steam Engine, with force or well pumps.
Elevation. Scale 1/48th.

expansive working available, reciprocating weights have been employed—the equivalents of fly-wheels—or to Worthington's compensating pumps noticed at page 344: storing energy in the beginning of the stroke, and dispensing it towards the end.

In the new form of pumping engine, figs. 1019, 1020, and 1023, the pump

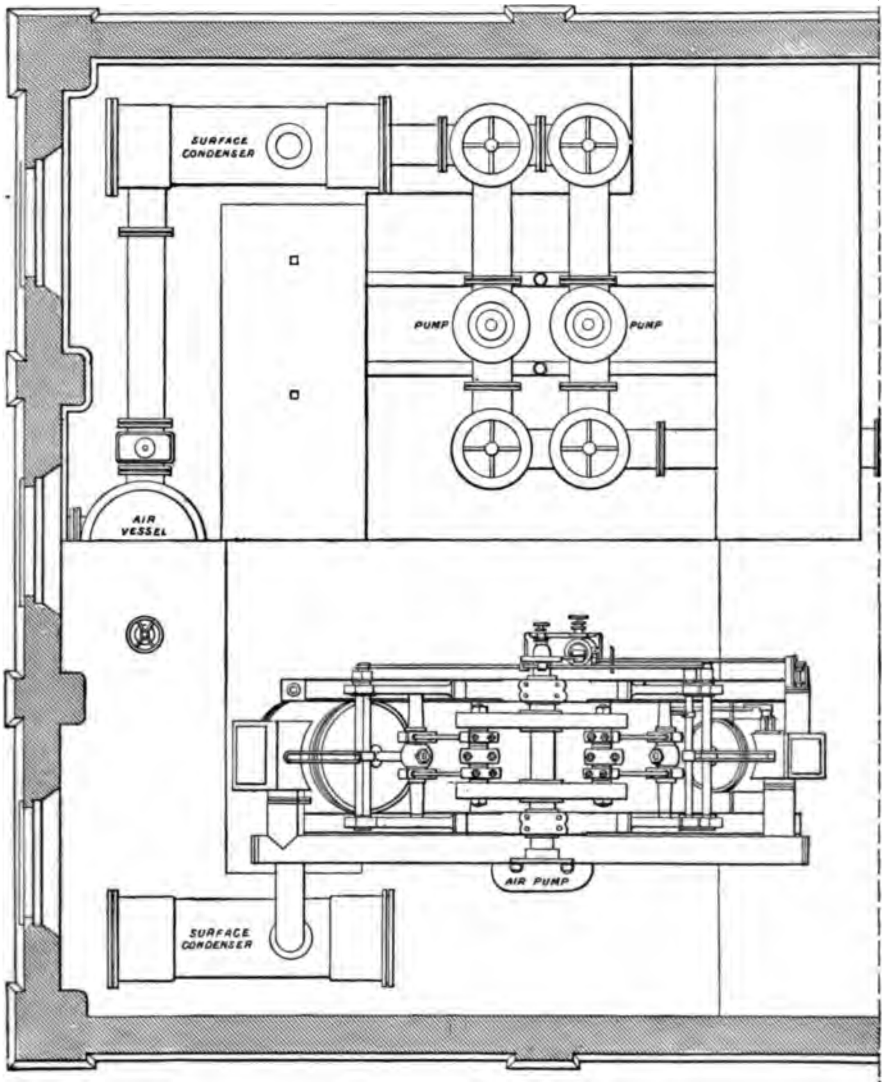
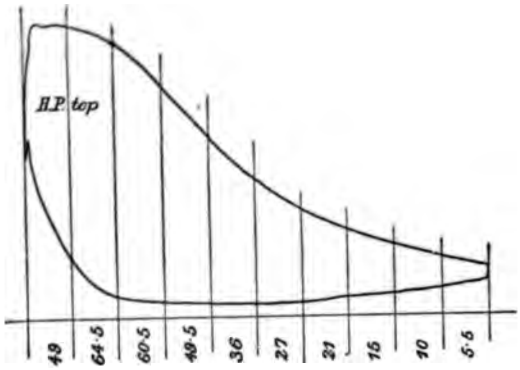


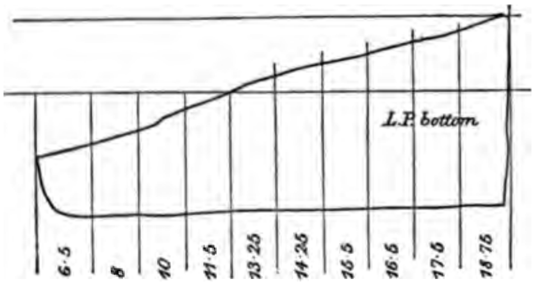
Fig. 1020.—Davey Compensating Compound Pumping Steam Engine. Plan. Scale 1/48th.

resistance diagram approximates in form to the combined steam diagrams, and so by such a compensating means dispenses with the reciprocating weights, whilst enabling the engine to work at high rates of expansion. A diagram of the arrangement is given in fig. 1021. *a, a* are the pumps; *b, b*, trunk guides for the pump-rods; *c, c*, the first and second steam cylinders;

and at two-thirds in the second cylinder. At a speed of 10 strokes per



First Cylinder. Effective mean pressure, 33.8 lbs. per square inch.



Second Cylinder. Effective mean pressure, 13.175 lbs. per square inch.

Figs. 1025.—Davey Pumping Engine: Indicator Diagrams. Vacuum, 26 inches.

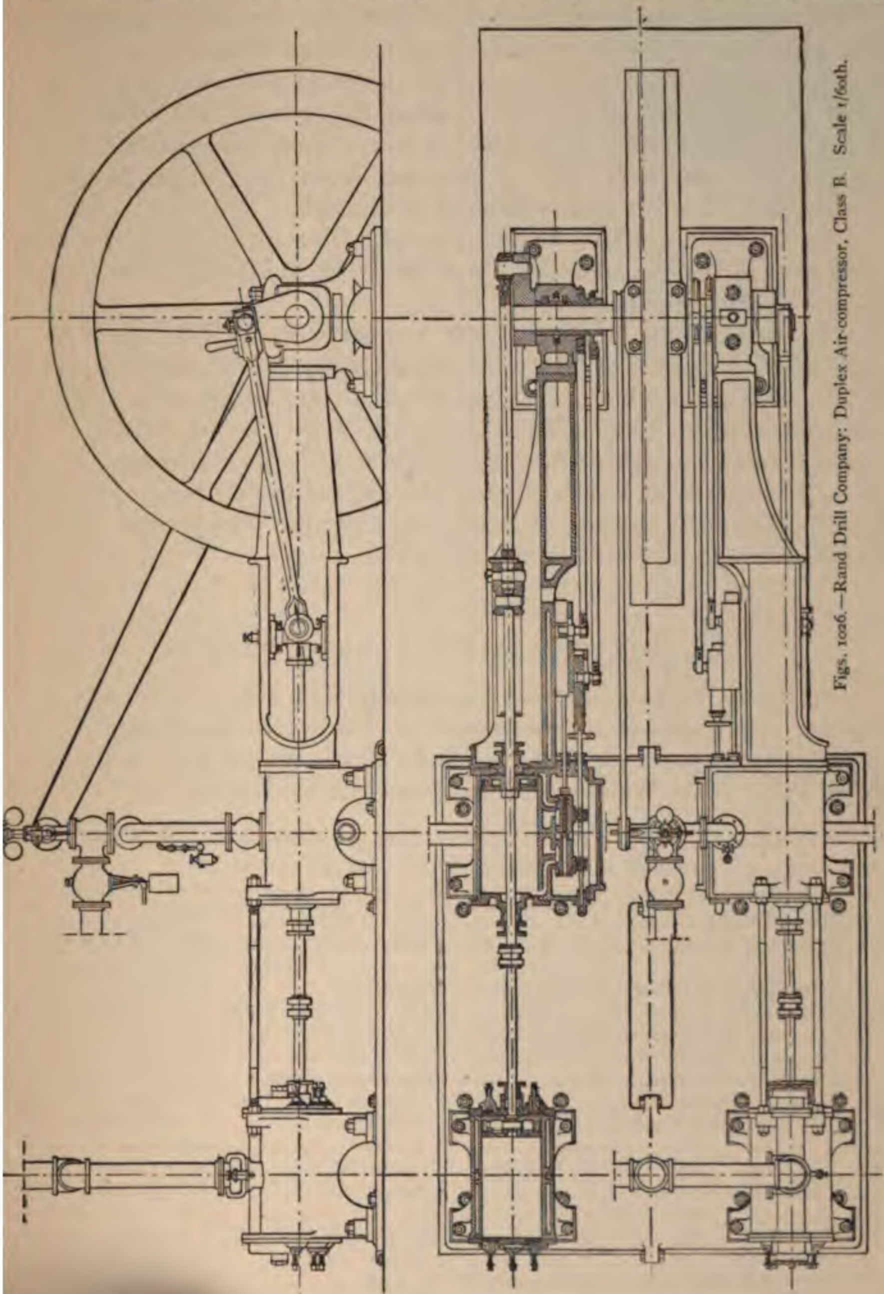
minute the consumption of feed-water is stated to be 16 pounds per indicator horse-power.

XIV. DUPLEX AIR-COMPRESSING ENGINE.

CONSTRUCTED BY THE RAND DRILL COMPANY.

The duplex air-compressor, figs. 1026, consists of a pair of horizontal steam cylinders, side by side, working to a main shaft and fly-wheel, with cranks at right angles; and a pair of air-compressing cylinders behind the steam cylinders, worked by prolongations of the piston-rods. The cylinders are all of one size: 18 inches in diameter, with a 30-inch stroke. The stress of compression is necessarily very unequal—commencing the stroke at nothing, and ending it with the maximum stress; whilst the stress of the steam in the cylinder commences at the maximum and ends by expansion and exhaust at a minimum. Thus the stress and counter-stress of the steam and the air at each side do not match. But this objection is removed when the two semi-engines are paired, so that the steam-stress on one side, applied to the crank at the top or the bottom centre wher is at its maximum leverage, balances the ma air-stress on the

de at the end of the stroke, when the crank is at its minimum leverage
n the end centre. Each semi-engine in reality works the compressing



Figs. 1026.—Rand Drill Company: Duplex Air-compressor, Class B. Scale 1/60th.

e side. A balance being in this way brought a
ate size is sufficient for maintaining steady

Nevertheless, the fly-wheel is made very heavy, in order to gain steady motion when it is desired to work with only one side of the engine.

The engine is fitted with the Meyer valve-gear for each cylinder, adjustable while the engine is in motion; and with an ordinary ball-governor. A pressure-governor is connected to the ordinary governor, to slacken the speed whenever the air-pressure reaches the desired maximum, usually 65 lbs. per square inch. It is attached to the compressor pipes. The air-plunger and steam-valve are on the same rod; the plunger is weighted directly, and ensures a steady pressure of air.

The frames are of the Corliss pattern. The air-cylinders and steam-cylinders are tied together by a sole-plate, to which they are fixed, and tie-rods at the upper part.

The air-cylinders are fitted with poppet valves. The cylinders are made of hard brass, the better to conduct away the heat of compression, as thin as is practicable. The cylinder heads are hollow, and have water circulated through them. The pistons and their rods are hollow, and by means of telescopic tubing they are kept supplied with cold water.

According to the results of tests, the engines can do their work with a consumption of 25 pounds of steam per indicator horse-power per hour. The engine makes 75 revolutions per minute.

XV. THE VICARS MECHANICAL STOKER.

The Vicars mechanical stoker has already been noticed, page 333, vol. i., together with results of its performance. The results of comparative trials recently made (June, 1890) of the Vicars stoker against hand-firing, at the Royal Paper Mills, Wandsworth, are given in table No. 197:—

Table No. 197.—Trial of the Vicars Mechanical Stoker versus Hand-firing with Forced Draught.

1. Date of trials	June 23, 1890	June 24, 1890.
2. System of stoking	Vicars'	Hand-firing, with forced draught.
3. Description of boiler	Lancashire	Lancashire.
4. Dimensions of shell	30 ft. long × 7 ft. 5 ins.	30 ft. long × 7 ft. 5 ins.
5. Diameter of furnace-tubes	2¼ feet	2¾ feet.
6. Duration of trials	10 hours	10 hours.
7. Designation of coal	Bituminous slack	Welsh small.
8. Total grate-area	22 square feet	33 square feet.
9. Total coal consumed	2 tons 13 cwts.	3 tons 4 cwts.
10. Do. do. per hour	5.3 cwts.	6.4 cwts.
11. Do. do. per sq. ft. of grate	27 pounds	21.7 pounds.
12. Total water evaporated	5330 gallons	5020 gallons.
13. Do. do. per hour	533 "	502 "
14. Do. do. per pound of coal	8.08 pounds	7 pounds.
15. Price of fuel	13s. per ton	15s. per ton.
16. Cost for fuel per 1000 gals. evaporated	6s. 5.5d.	9s. 4.75d.

At Horton Kirby Paper Works, South Darenth, Kent, an economy of 12.56 per cent is effected by the Vicars Stoker, burning the same [illegible]aton small.

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AND

THE PRINCIPLES, CONSTRUCTION, AND PERFORMANCE OF STEAM ENGINES— STATIONARY, PORTABLE, LOCOMOTIVE, AND MARINE, EXEMPLIFIED IN ENGINES AND BOILERS OF RECENT DATE.

ILLUSTRATED BY ABOVE 2000 FIGURES IN THE TEXT, AND A SERIES OF FOLDING PLATES, DRAWN TO SCALE.

BY

DANIEL KINNEAR CLARK,
M.INST.C.E., M.I.M.E.,
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Author of "Railway Machinery;" "A Manual of Rules, Tables, and Data for Mechanical Engineers;" "The Exhibited Machinery of 1862;" "Tramways: their Construction and Working;" &c.

VOLUME I.

BLACKIE & SON, LIMITED,
LONDON, GLASGOW, EDINBURGH,
AND NEW YORK.
1891.

PREFACE.

This Work is intended to provide a comprehensive, accurate, and clearly written text-book, fully abreast of all the recent developments in the Principles, Performance, and Construction of the Steam Engine, the need for a work of this kind having long been acknowledged.

Written in full view of the great advances of modern times, it expounds the underlying principles of Steam and the Steam Engine, and describes the present practice, exemplified in the construction and use of modern Engines and Boilers, in all their varieties of form:—Stationary, Portable, Locomotive, and Marine. In order to produce a satisfactory work on this subject, the author has availed himself of the numerous published records of investigation and practice—British, American, and Continental, and has added thereto the results of his own investigations, based on direct experimental inquiry carried on during many years.

The work is divided into four main sections:—I. The Principles and Performance of Steam Boilers. II. The Principles and Performance of Steam Engines. III. The Construction of Steam Boilers. IV. The Construction of Steam Engines.

In carrying out this arrangement upwards of two hundred steam engines and boilers are described and illustrated. The engines are of every variety—simple, compound, multiple-expansive; stationary for general purposes, and for mills, pumping, winding, blowing, &c.; portable engines, locomotives—railway and tramway; and marine engines. The boilers, likewise, are of numerous types. Chapters are devoted to the principles of riveting and the strength of riveted joints, the strength of shells and flat plate-surfaces, the resistance of flue-tubes; the equilibration or balancing of engines, valve gears, the action of governors, the behaviour of steam in the cylinder, and the best proportions for cylinders single and compound. Matters such as the advantage of superheating steam, steam-jacketing of cylinders, the best ratios for expansive working, the best ... of compression of steam in the cylinder are determined; while ... of the Woolf Engine *versus* the Receiver Engine, Compound ...-expansion, Quadruple-expansion Engines, and other cog-

nate subjects—with special reference to locomotive and marine practice—are fully discussed.

The efficiency of Steam Boilers is fully investigated;—the properties of steam, principles of combustion, the distribution of heat in the boiler, the relative effectiveness of different portions of the heating surface, and the best proportions for evaporative performance. The subject of fuels—solid and liquid—is largely treated, with results of many systematic trials of fuels and furnaces. The various contrivances for effecting complete combustion of fuel and preventing smoke, the most suitable conditions for attaining that object, the principles of draught and the proportions for flues and chimneys, are fully considered in all their relations. Forced draught, in its various forms, is described and illustrated.

The Work is illustrated by above 2000 figures in the text, consisting of engines, boilers, details, and diagrams, and by a series of large plates of complete engines and boilers drawn to scale.

The list of Contents which will be found in each volume shows the comprehensive character and scope of the work. A full Index at the end enables the information on all points to be readily referred to.

D. K. CLARK.

LONDON, *August*, 1890.

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